Microelectronics and Optoelectronics Laboratory & Thin Film Physics Group - Annual Report 1998

Report

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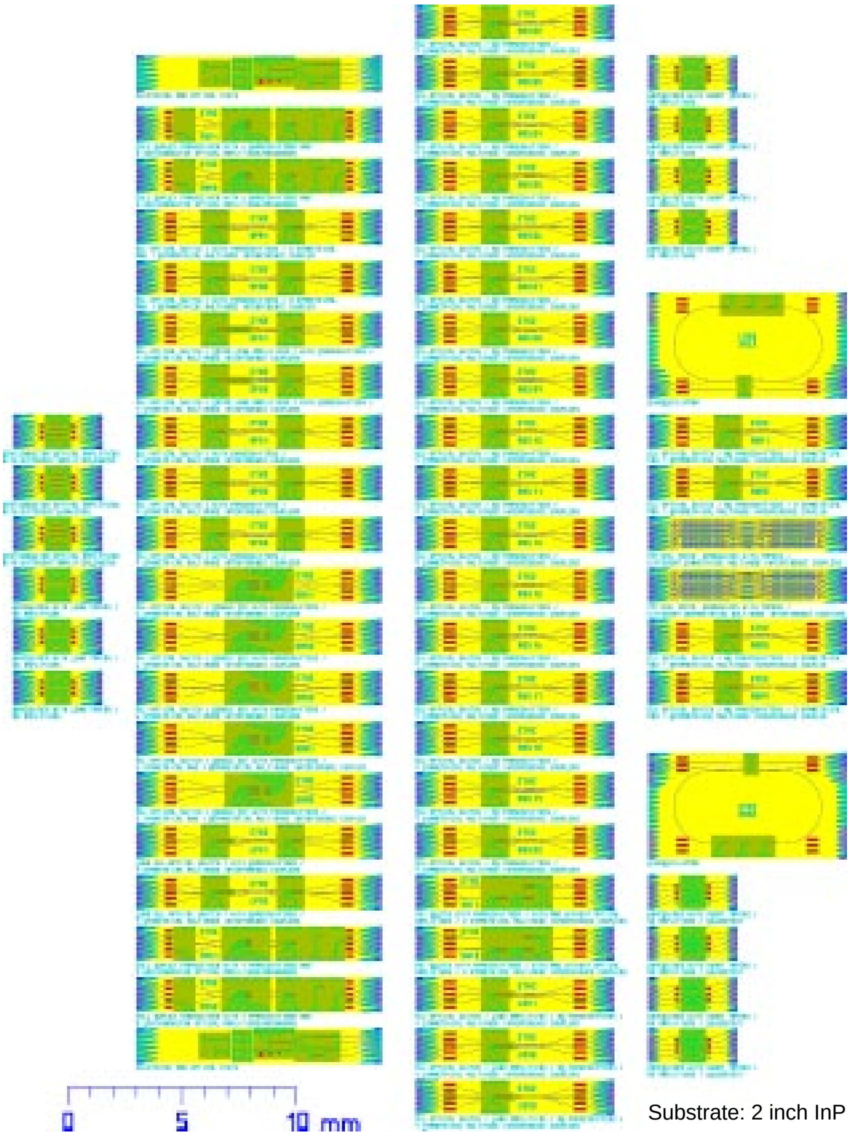
Publication date:
1999

Permanent link:
https://doi.org/10.3929/ethz-b-000325645

Originally published in:
Microelectronics and Optoelectronics Laboratory & Thin Films Physics Group - Annual Report

MICROELECTRONICS AND OPTOELECTRONICS LABORATORY



Substrate: 2 inch InP

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Optically controlled optical waveguide switches realized in Indium Phosphide as Mach-Zehnder interferometers with semiconductor optical amplifiers in their arms

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RESEARCH SUMMARY

The research activities of the Microelectronics and Optoelectronics Laboratory rely heavily on the three-five compound semiconductor epitaxy and device development capability, built-up within the group over the years. Its Metal-Organic Chemical Vapor Deposition (MOCVD) epitaxy serves, on one hand, for the development of optoelectronic waveguide components and high-speed electronics in Indium Phosphide quaternaries, and on the other hand, for the realization of quantum-well and quantum-wire structures in Gallium Aluminium Arsenide through the group of Prof. E. Kapon of the École Polytechnique Fédérale de Lausanne. Three scientists, a laboratory technician and all the device developers share the technology and device developments as well as the running and maintenance of the device fabrication facility. The three-five compound semiconductor physics and optoelectronics device technology capabilities are flanked by design activities in silica on silicon optical waveguide components and in high-speed electronics. The optoelectronics and high-speed electronics research is essentially driven by applications in fiber optical communications.

Research highlights of 1998:

- Optically controlled optical waveguide switches for multi-ten Gigabit/s signal multiplexing, demultiplexing and wavelength conversion.

- Optically controlled optical switch modules consisting of monolithic InP Mach-Zehnder interferometer with semiconductor optical amplifiers in their arms and waveguide-tapers for low loss coupling to optical fibers.

- Physical modeling of optically controlled waveguide switches taking picosecond refractive index- and gain dynamics into account.

- Forty Gigabit/sec photodetector receivers for 1.3 and 1.55 micrometer wavelengths realized in InGaAs/InP-photodiode-heterobipolar transistor technology.

- Wavelength-division-multiplex (WDM) filters in silica on silicon featuring 16 channels with low insertion loss, low crosstalk and complete insensitivity to polarization at standardized 200 GHz-spaced frequencies in the 1.55 micrometer wavelength range.

- Thermooptic silica on silicon waveguide switches with submillisecond switching times, insertion losses below 1 dB and on-off ratios exceeding 20 dB.

- Semiconductor optical amplifiers and amplifier gates for 1,3 and 1,55 micrometer wavelengths featuring high polarization independent gains.

- Quantum Hall effect devices in an effort with the group of Prof. Ensslin.

- Four wave mixing in semiconductor optical amplifiers, resulting in wavelength conversion over 30 nm at 10 Gb/s, dispersion compensation by mid-span spectral inversion, and efficiency flattening and equalization of frequency up- and down-conversion.

- Microwave photonics and data transmission on optically generated millimeter-waves at 60 GHz using a dual-polarisation emission external cavity diode laser.

- Semiconductor optical amplifier assisted Sagnac interferometer and applications as NOT, AND and XOR gates, and all-optical shift register at 10 GHz.

Several of the optoelectronic and high-speed electronic device developments for fiber optical communication projects of the European Union (EU) are coming to completion. They include optically controlled optical time domain demultiplexer/wavelength division (OTDM/WDM) transmultiplexers for the ACTS Project OPEN, InP space switches, SiO_2/Si wavelength-division-multiplex-(WDM)filters and Gigabit/s 200 mA driver electronics for optical amplifier gates of the ACTS KEOPS project, photodetectors, transmitter- and receiver-electronics for the COBNET, WOTAN and RODCI projects. Ongoing projects include internal as well as directly industry financed and national foundation projects, and the EU-projects HIGHWAY, OIIC and SONATA. In addition, we are involved in the European COST-framework, have co-ordinated and completed a COST-project on photonic devices for telecommunications, and are active in several COST-projects in telecommunications and physics.

We acknowledge the support of the "Bundesamt für Bildung und Wissenschaft (BBW)", the "Swiss Nationalfonds", the "Kommission für Technologie und Innovation" and the Schwerpunkts-Programm Optique of the Swiss Federal Institute of Technology. We also acknowledge the support by the Japanese Ministry of Postal Services for the research co-operation between our group and the Yamagata University.

We are encouraged, that several of our optoelectronics device and packaging developments and optical interconnect transmitter and receiver designs are of interest to industry and actively exploited commercially, thereby creating jobs at two start-up companies: Opto Speed SA, Mezzovico, Ticino and Helix AG, Zurich.

The **Thin Film Physics Group,** associated with our laboratory, is, under the leadership of Dr. Zogg and Dr. Tiwari, active in the physics and development of compound semiconductors, such as PbTe/PbSnSe, $CuInSe_2$, $CuGaSe_2$ and CdTe/Cds for infrared detection and solar cell development. In addition, wide bandwidth AlGaAs/CaF_2 quarter wavelength stack mirrors and saturable absorbers intended as key elements for the generation of ultrashort laser pulses are developed (see report of Prof. U. Keller). For layer growth, various physical vapour deposition methods, including MBE (Molecular Beam Epitaxy) are used.

Highlights of 1998 include:
Narrow bandgap materials for infrared sensors:

- One- and 2-dimensional infrared sensor arrays for thermal imaging in e.g. epitaxial PbTe on Si-substrates that may contain active circuits.

- Study and reduction of dislocations to <106 cm-2 in lattice mismatched epitaxial PbSe on Si(111).

Solar cell research:

- Fabrication processes for polycrystalline $CuInGaSe_2$ thin film solar cells with ~14% efficiency.

- CdTe solar cells with 11% efficiency by vacuum evaporation and recrystallization.

- Highly transparent (>85%) and conducting (sheet resistance < 10 Ohms/square ZnO:Al layers grown by RF magnetron sputtering.

- Growth of $CuIn_{2.5}Se_4$ single phase epitaxial layers and aqueous solution epitaxy of CdS on $CuInSe_2$.

- Identified nanometer sized Cu_xSe precipitates, limiting the photovoltaic properties of Cu-rich $CuGaSe_2$ solar cells.

Educational Activities

The teaching activities of the Microelectronics and Optoelectronics Laboratory and of the Thin Film Physics Group in 1998 included a two-semester course in Semiconductor Electronics and Integrated Circuits with device fabrication in the laboratory by H. Melchior and J. Schmid, courses in Fiber Optical Communication and Optoelectronics by G. Guekos and H. Melchior, a course in Diode Lasers and Optoelectronics by H. Melchior, a course in Solar Cells by G. Guekos, a two-semester course in Electronics for physics students by J. Schmid and R. Zinniker and a two-semester course in Thin Film Physics and Technology by H. Zogg. The group is also actively involved in laboratory exercises for physics and electrical engineering students.

Our research and educational activities in 1998 resulted in several diploma theses and eight doctoral theses.

We are engaged in helping universities and research institutions in developing countries to enhance their teaching and research capabilities in fiber optical communications. Since several years we are involved in the organisation of regional courses in South-East Asia and Africa and we support practical work in local laboratories.

ORBITUARY

On January 2nd, 1999

Dr. Jürg Schmid,

our longtime groupleader, lecturer
and specialist in semiconductor
technology and device fabrication
passed away quite unexpectedly.
He died from a heart-attack.

In Dr. Jürg Schmid we loose the scientist who contibuted the most both to putting our three-five compound semiconductor device technology laboratory in place and to instigate round procedures for its operation. In addition, Jürg Schmid was very creative in developing new device processes and electronic circuits.

Jürg Schmid was born March 11th, 1946 in Zurich, where he also went to school. He studied physics at the Swiss Federal Institute of Technology in Zurich, earning a Physics Degree in 1971. From 1972 to 1974 he worked as silicon device technology developer for the Swiss silicon integrated circuit manufacturer FASELEC. In 1975 he returned to the Swiss Federal Institute of Technology, first to head a small silicon integrated circuit laboratory and to complete a doctoral thesis. Then he became lecturer in electronics and was leading a group responsible for the development of three-five compound semiconductor technology and high-speed indium phosphide heterobipolar transistors.

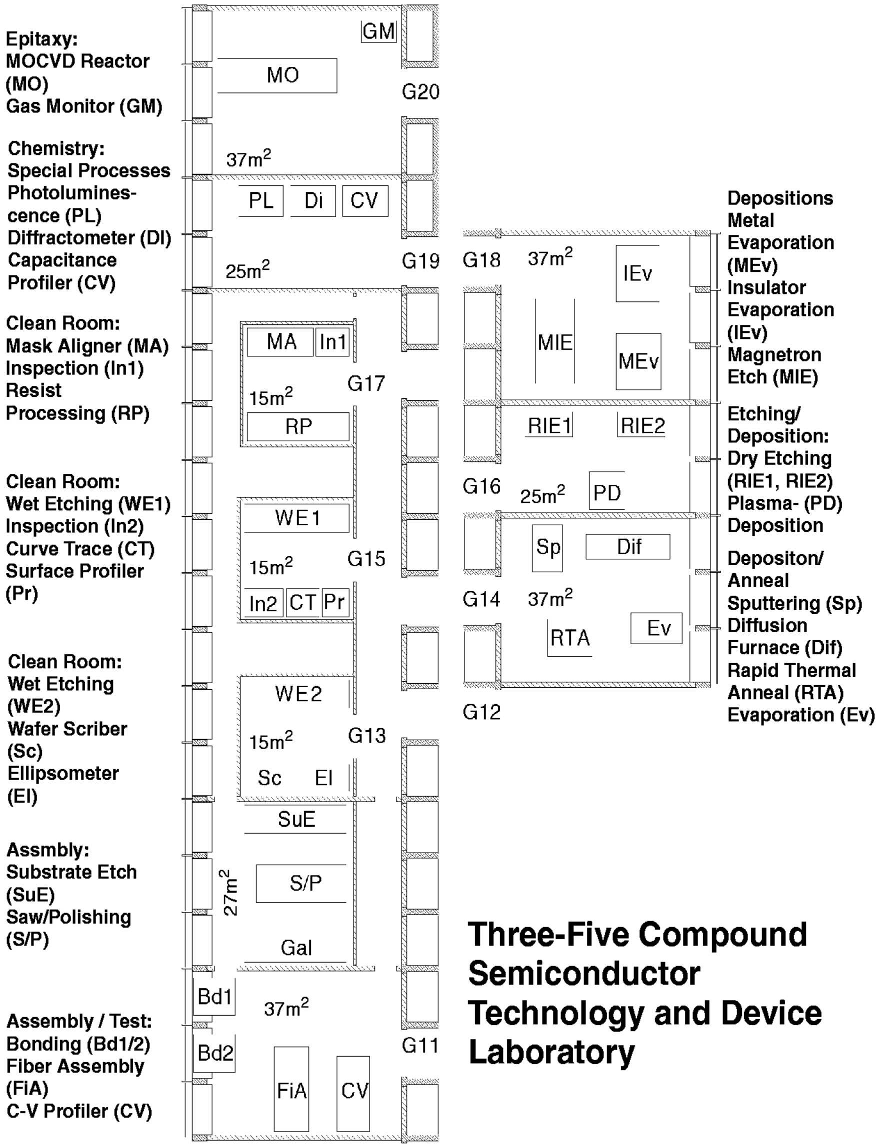
Jürg Schmid was very talented in device technology developments. With his ideas, profound technology knowhow and his sound judgement, he helped and inspired the entire group and his students.

He leaves behind his wife Verena and his son Martin.

Three-Five Compound Semiconductor Device Fabrication Laboratory

E. Gini, J. Schmid, W. Vogt, R. Bauknecht, M. Blaser, M. Bitter , E. Gamper, C. Holtmann, M. Ebnöther and H. Melchior

For the optoelectronic waveguide device and the high-speed electronics developments, the microelectronics and optoelectronics group relies on a three-five compound semiconductor device laboratory that has been built-up over the years. Metalorganic chemical vapor deposition (MOCVD) serves to grow epitaxial layers, both InP-based optoelectronic waveguide devices and high-speed heterobipolar electronics and for GaAs-based multi-quantum-well and quantum-wire lasers (the later for Prof. E. Kapon and his group at the Swiss Federal Institute of Technology in Lausanne). The epitaxy growth facility is complemented by planar processing capabilities, including contact lithography, plasma- and wet etching, thin film chemical vapor deposition, evaporation and sputtering.



Three-Five Compound Semiconductor Technology and Device Laboratory

Low Pressure Metal Organic Vapor Phase Epitaxy for III-V Compound Semiconductors

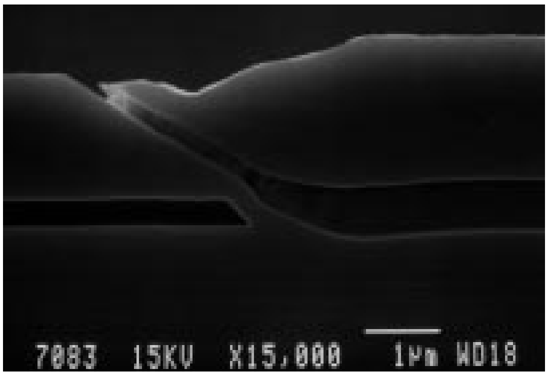
E. Gini

Low pressure metal organic vapor phase epitaxy (LP-MOVPE) is used to grow III-V compound semiconductor materials with excellent control over their structural and electrical characteristics. MOVPE permits a fine control of layer thickness, interface structure, material composition, and impurity concentration. Very thin structures can be grown for investigating quantum effects and dimensionally reduced systems are easily fabricated.

At our Institute we almost completely rely on the MOVPE technique for the growth of epitaxial layer structures. We have one MOVPE system installed with six hydride lines and eight metal-organic lines to satisfy the demands of the large variety of layer structures needed for the studied devices. The flexibility of our systems allows us to grow $In_{1-x}Ga_xAs_yP_{1-y}$/InP as well as $Al_xGa_{1-x}As$/GaAs structures in the same reactor. Layers with excellent purity (background doping below $10^{14}/cm^3$), layers for low loss optical waveguides (propagation loss less than 0.5 dB/cm), and structures for high performance InGaAs junction field effect transistors (JFET) as well as InP heterojunction bipolar transistors (HBT) are being grown.

For the characterization of the grown layers x-ray diffraction and room-temperature photoluminescence are routinely used. For the study of interface quality we have also access to secondary electron microscopy (SEM) and to transmission electron microscopy (TEM). Doping concentrations are determined either by Hall-measurements or by capacitance-voltage profiling.

In 1998 the control system of our MOVPE equipment was completely renewed. New features were added, for example ramping of process parameters, or automatic calculation of source consumptions. Data logging allows for a better quality control. Our research included the optimization of growth parameters for AlGaInAs, the realization of new buried waveguide structures and the development of a growth sequence for the realization of high speed all-optical switches including up to six growth steps.

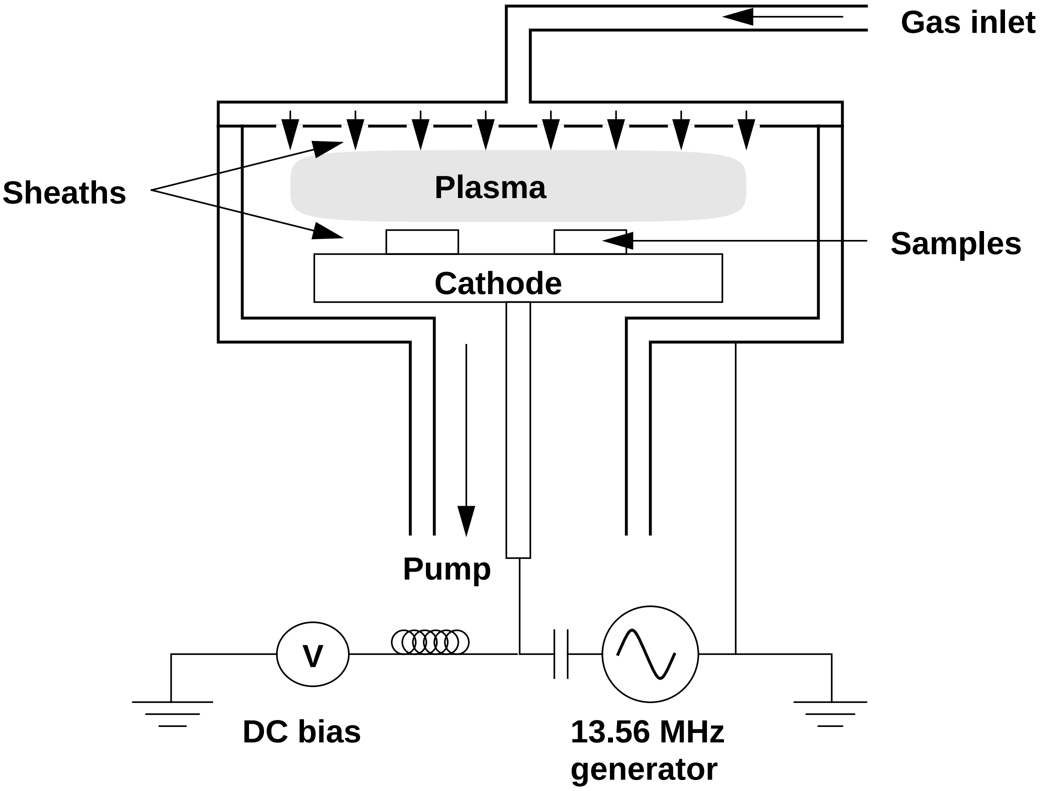


SEM picture of an interface between an amplifiers structure (left) and a passive waveguide (right).

Plasma Etching

E. Gini

Today, state-of-the-art integrated circuit manufacture depends on the mass replication of tightly controlled, micron-sized features in a multeity of materials.
At our Institute a variety of equipment for the dry etching of optoelectronic integrated circuits is available. Commonly used are two conventional parallel plate reactors as schematically described in the figure below .



Schematic view of a parallel plate reactor.

Plasma etching processes for the definition of InP based waveguides and optical switch structures are based on mixtures of the gases H_2, CH_4 and Ar. Process parameters as gas flows, chamber pressure, RF power density are optimized in order to achieve a high selectivity to the mask materials and a good homogeneity. Etch depth variations as low as ±1.5% have been achieved over a 2-inch wafer.
The same type of system is used for the dry etching of Ti and SiO_x layers using fluorine chemistry. These layers are used as mask material that are capable to withstand high temperatures. The etching of optical silica waveguides is done on the same system. In addition we have the capability to etch polyimide, PMMA or to ash organic residues with an oxygen plasma. Both etching systems are computer controlled and a number of standard processes are installed. A user-friendly menu allows people from our but also from external reserarch groups to run their dry-etching processes themselves without the need of profound technical knowledge.

Low Dimensional Semiconductor Nanostructures

A. Rudra, A. Hartmann, G. Biasiol, F. Lelarge, K. Leifer, A. Condo, A. Sadeghi, E. Martinet, C. Constantin, H. Weman, D. Oberli, L. Sirigu, M. A. Dupertuis, E. Kapon
(Institute for Micro and Optoelectronics, EPFL),
E. Gini, R. Bauknecht, H. Melchior (IQE-ETHZ)

This area of research covers the growth of quantum nanostructures and the evaluation of their optical properties in the perspective of their integration in optoelectronic devices. GaAs/AlGaAs and InGaAs/(Al)GaAs quantum wires (QWRs) and quantum dots (QDs) are obtained using low pressure Organometallic Chemical Vapour Deposition (OMCVD) on corrugated GaAs substrates. A selection of recent experimental observations is given here.

Growth behaviour on non-planar substrates

We have extended our understanding of the self-ordering of nanostructures on non-planar surfaces, regarding both the lateral as well as the longitudinal structural features. In particular, we have developed an analytic model describing the self-limiting growth and a Monte Carlo simulation shedding light on the process at the atomic level. The predictions of the model have been successfully verified on our OMCVD grown profiles. They can be used to design and optimize a variety of nanostructures, including QWRs, vertical quantum wells, and QWR superlattices in the GaAs/AlGaAs system.

The method of growth on nonplanar patterned substrates has been extended for the fabrication of QDs. These novel GaAs/AlGaAs QD structures display a superior size homogeneity and can be individually positioned as well as arranged in dense arrays. So far, studies of the PL recombination of single and multiple excitons in single QDs have been carried out.

QWRs in microcavities

Arrays of InGaAs/GaAs QWRs exhibit narrow (8meV) and efficient PL emission at low temperature. Similar QWRs, embedded in a planar microcavity allowed us to investigate the transition from resonant to non-resonant coupling between 1D electron and 2D photon states. At resonant coupling, a clear spectral and angular redistribution of the QWR emission into a narrow (1meV) and directional resonant quasi-modes of the microcavity results in an on-axis emission intensity enhancement factor of about 50. A microcavity-induced alteration of exciton relaxation was also observed in the weak coupling regime. The lateral carrier confinement in the wires gives rise to a characteristic polarization anisotropy of the luminescence and absorption spectra. Thus, the combined effect of carrier and photon confinement in our QWR-microcavities is potentially useful for making high efficiency QWR LEDs and lasers with polarization control.

QWR LEDs and lasers

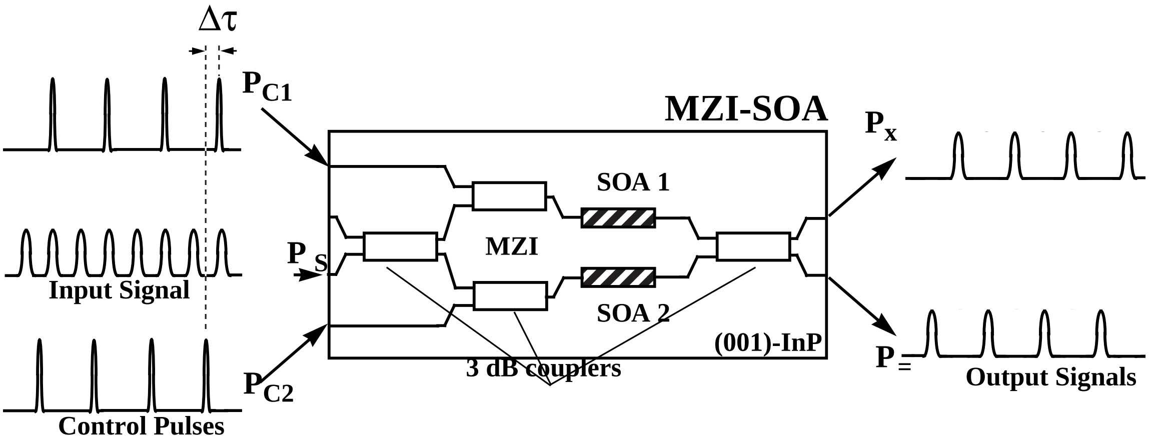
Selective current injection was observed into V-groove GaAs/AlGaAs QWRs embedded in p-n junctions leading to efficient electroluminescence solely from the QWRs up to room temperature. I-V characteristics show a reduction of the turn-on voltage as compared with otherwise similar QW diodes, which is explained by the bandgap reduction at the vertical QW region connected to the wires. These results show a route for a significant reduction in current densities in QWR LEDs and lasers, as compared with QW devices.

We have optimized edge-emitting GaAs/AlGaAs QWR structures by investigating the effect of waveguide geometry, position and number of QWRs using a vectorial eigenmode model. The results of the numerical calculations as well as measurements using Scanning Near Field Optical Microscopy (SNOM) reveal the formation of a highly confined (<0.5 m FWHM) optical mode due to the V-shape geometry of the waveguide. The maximum of the heart shaped mode is found to be shifted upward with respect to the center of the waveguide. 3 QWR lasers exhibited lasing at a wavelength close to 0.83 munder pulsed electrical excitation with 65mA threshold for 1mm long cavities.

Optically Controlled Mach-Zehnder Interferometer Switches for Optical Demultiplexing and Wavelength Conversion

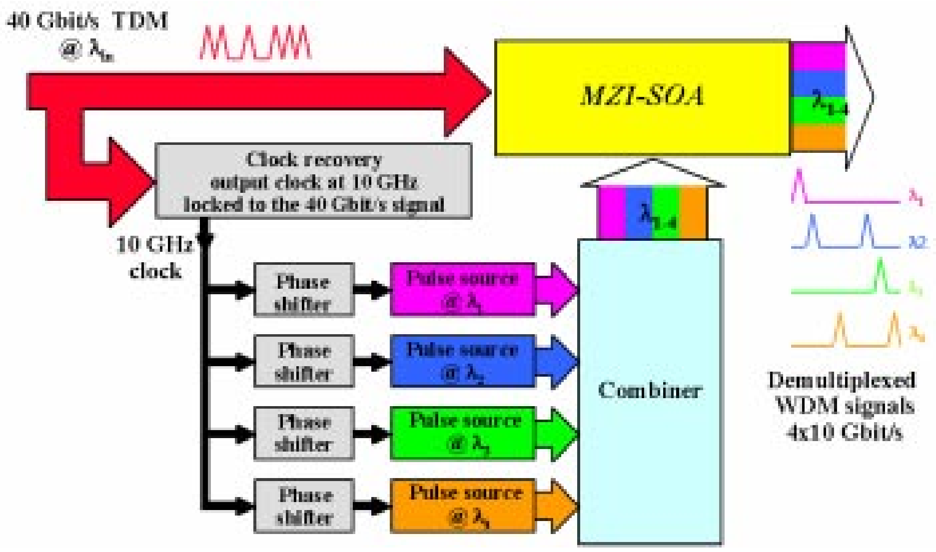
St. Fischer, M. Dülk, R. Hess, W. Vogt, E. Gamper, W. Hunziker, H. Melchior

Optically controlled demultiplexers based on InP-waveguide Mach-Zehnder interferometers (MZI) with monolithically integrated semiconductor optical amplifiers (SOA) as phase changing elements have shown capabilities for 40 and 80 to 10 Gb/s OTDM demultiplexing.



All-optical demultiplexer consisting of MZI-SOA structure controlled by two synchronised sequences P_{C1} and P_{C2} of short (picosecond), temporally delayed (Δτ), optical control pulses. Device operates in the 1.55 μm wavelength range.

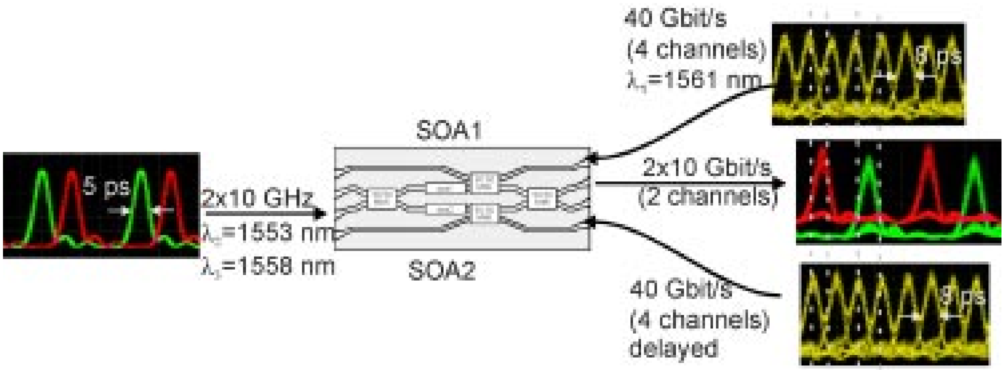
At network interfaces a way to convert a 40 Gb/s OTDM RZ signal at one wavelength into 4x10 Gb/s signals at 4 different wavelengths is needed (OTDM/WDM transmultiplexer). We demonstrated the possibility to realize such an interface with one MZI-SOA, using 4 properly synchronized pulse sources and a differential input scheme for the OTDM 40 Gb/s signal.



All-optical OTDM/WDM Transmultiplexer

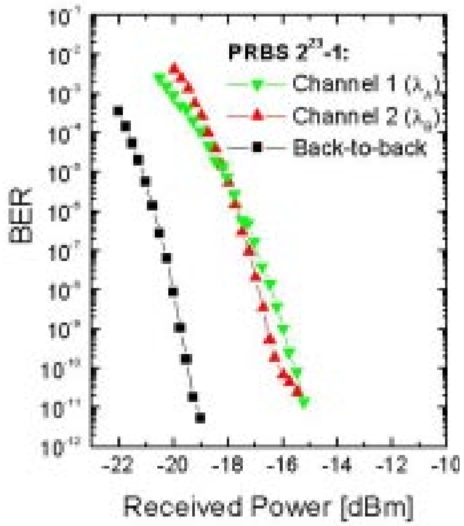
St. Fischer, M. Dülk, E. Gamper, W. Vogt, W. Hunziker and H. Melchior

In optical networks it's a fundamental requirement to convert data from high-speed optical time division multiplexed (OTDM) transmission trunks to lower-speed wavelength division multiplexed (WDM) trunks. This means that the OTDM data has to be demultiplexed in its different channels with lower bit rate. In the WDM network each channel has to have a different wavelength which demands wavelength conversion of the demultiplexed channels.



OTDM/WDM Transmultiplexer: Two channels are extracted out of four and converted to different wavelengths.

An elegant way to perform these two steps (demultiplexing and wavelength conversion) simultaneously is to use one single monolithically integrated Mach-Zehnder interferometer (MZI) with semiconductor optical amplifiers (SOAs) in its arms. Using the OTDM signal as optical control pulses which switch the output of the MZI from one port to the other and back again, we can use the MZI-SOA as a modulator for pulsed wavelength sources. The working principle of the so-called OTDM/WDM Transmultiplexer is shown for an extraction/conversion of two channels out of four.

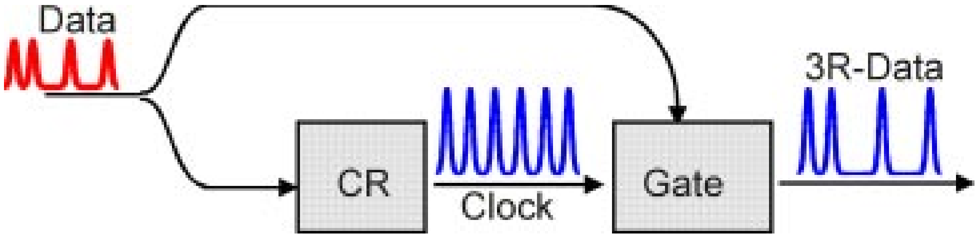


Bit-error rate (BER) assessments are performed in collaboration with CSELT, Italy, using a 40 Gbit/s (4x10 Gbit/s channels) data stream from which two channels were extracted. As new wavelength sources two gain-switched DFB lasers in conjunction with a fiber compression stage produced 5 ps short pulses which are modulated through the MZI-SOA. The penalty of 2.6 dB will hopefully be reduced in further experiments with four wavelength sources.

All-Optical Signal Regeneration

St. Fischer, M. Dülk, H. Melchior

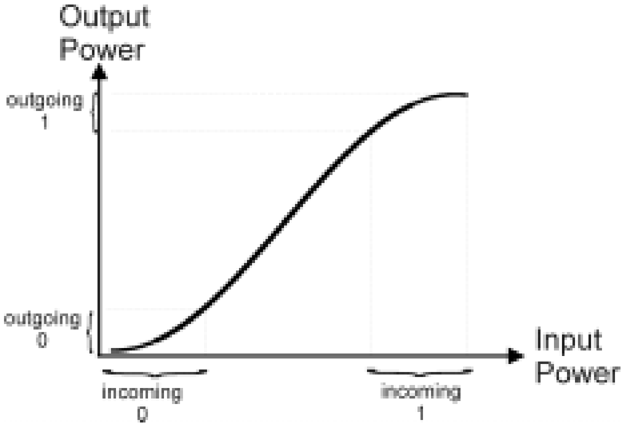
In transmission networks, pulse degradation through active or passive devices or just through long fiber transmissions have to be compensated to avoid errors of the transmitted data. For that regeneration technics will become key-elements in the future network designs. To overcome the electronic bottle-neck with increasing data rates of up to 1 Tbit/s, we have to evade to the all-optical way to regenerate data. These so-called 3R technics (reshaping, retiming, reamplification) are based on two fundamental parts: the all-optical clock recovery (CR) and the decision gate.



Principle of all-optical regeneration (3R) with clock recovery (CR) and decision gate.

A very important part is the CR unit, which guarantees the three R's: right timing, optical power and the shape of the regenerated data. The decision gate is needed to determine whether the incoming bit is "1" or "0". It also has to impose this information on the clock pulses to form the regenerated data.

As all-optical CR unit we are going to use a mode-locked laser which will be optically modulated through the incoming data pulses that force the laser to pulse at its fundamental repetition rate.



Due to the transfer function of MZI-SOA's these devices can be used as decision gates

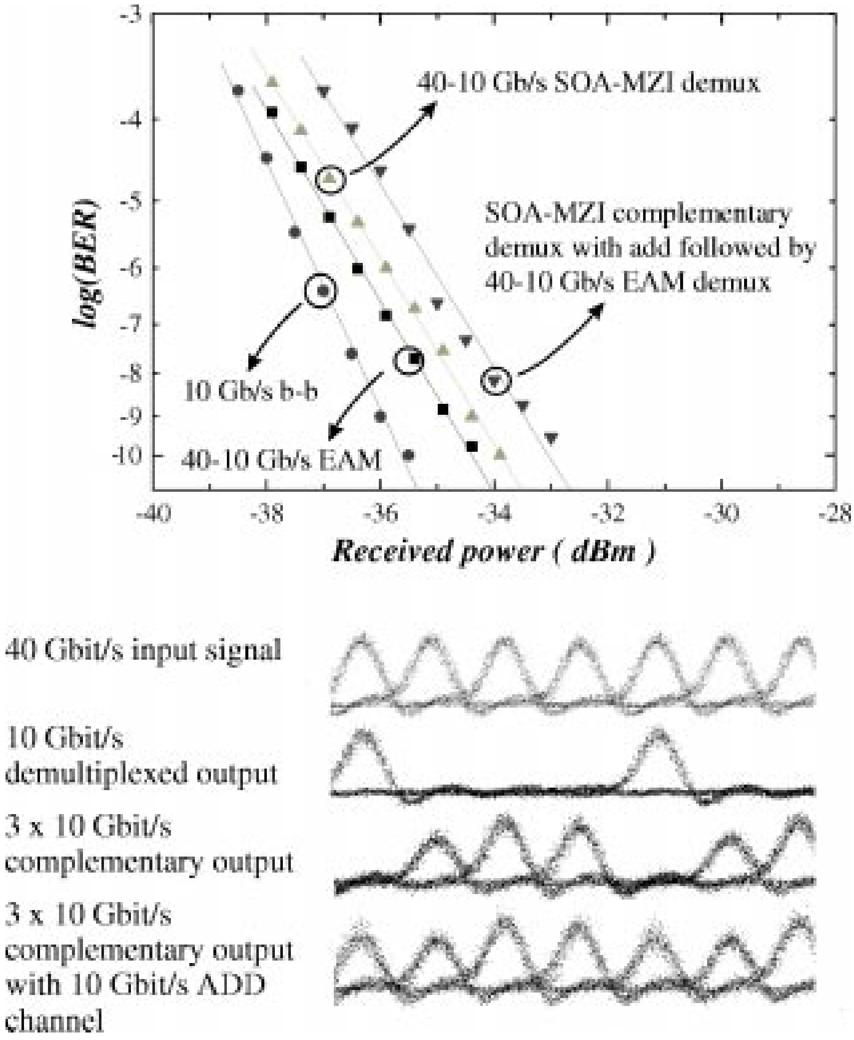
As decision gate we are using monolithically integrated Mach-Zehnder interferometers (MZI) with semiconductor optical amplifiers (SOA) in its arms. Due to its transfer function, incoming power levels can be clearly refered to "1"s or "0"s as is shown in the left figure.

40 Gbit/s Add/Drop Multiplexer

R. Hess, M. Dülk, W. Vogt, E. Gamper, E. Gini, P. A. Besse, H. Melchior

Optical time division multiplexing (OTDM) is well suited for long distance, high bit-rate transmission, e.g. for interconnecting large regional networks. A key component in an OTDM network is the all-optical add-drop multiplexer (AO-ADM), in which one or more channels are extracted from the bit sequence and new channels inserted into the vacant timeslot(s). In order to be able to re-use the extracted (or demultiplexed) channel, the AO-ADM must provide a complementary output for the optically cleared signal. In addition, a second input port for the signal to be added is needed. The possibility to simultaneously demultiplex and add a new channel is difficult to realize using already known methods. We have demonstrated for the first time that both regular demultiplexing and complementary demultiplexing with add-functionality can be performed simultaneously at 40 Gbit/s using a monolithically integrated Mach-Zehnder interferometer with semiconductor optical amplifiers (MZI-SOA).

Measured BER as a function of the received power at 10 Gbit/s for simultaneous add and drop operation, compared to the back-to-back reference (b-b). The sensitivity for the drop operation is -34.4 dBm and the total system penalty for clear/add operation (including EAM demultiplexing) is 2.4 dB resulting in a penalty for adding of 1.3 dB. The eye diagrams show the original 40 Gbit/s signal, the simultaneous MZI-SOA demultiplexing and the complementary demultiplexing without and with the 10 Gbit/s add channel.



Modeling of All-Optical Mach-Zehnder Interferometer Switches

M. Caraccia-Gross, R. Hess, M. Bitter, H. Melchior

A model has been developed to describe all-optical operations of monolithically integrated Mach-Zehnder interferometers (MZI) with semiconductor optical amplifiers (SOA's) in their arms. It includes amplified spontaneous emission (ASE), as well as gain compression and wavelength dependence of the gain and of the ASE. The propagation of the data (d) and of the control (c) signals through the SOA's is calculated with the help of the following rate equations for the power and for the phase:

$$\frac{\partial P_{d,c}}{\partial z}+\frac{1}{v_g}\frac{\partial P_{d,c}}{\partial t} = \left\{\frac{\Gamma g_l(N,\lambda_{d,c})}{1+(\varepsilon_{ch}+\varepsilon_{shb})P_{tot}}-\alpha_{int}\right\}P_{d,c}$$

$$\frac{\partial \phi_{d,c}}{\partial z}+\frac{1}{v_g}\frac{\partial \phi_{d,c}}{\partial t} = -\frac{1}{2}[\alpha_N-(\alpha_{ch}\varepsilon_{ch}+\alpha_{shb}\varepsilon_{shb})P_{tot}]\Gamma g_l(N,\lambda_{d,c})$$

where $g_l(N,\lambda)$ is the linear gain written with the help of the cubic formula:

$$g_l(N,\lambda) = a(N-N_{tr})-\gamma_1(\lambda-\lambda_N)^2+\gamma_2(\lambda-\lambda_N)^3,\quad \lambda_N=\lambda_{tr}-\chi_0(N-N_{tr})$$

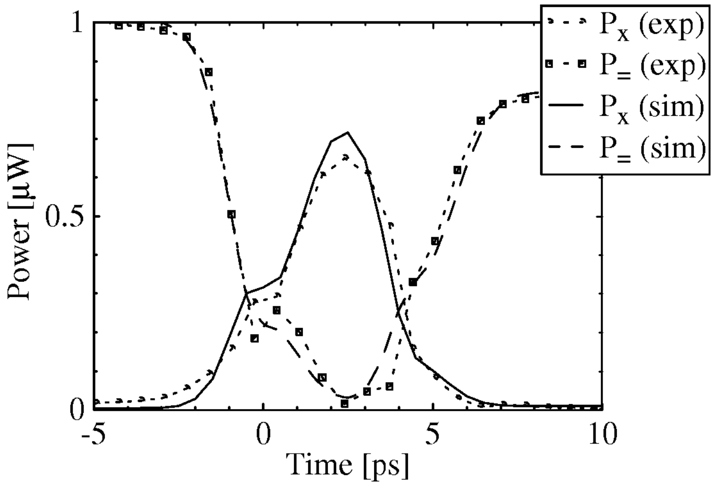
For the ASE power we have the following equation

$$\frac{\partial P^{\pm}_{sp}(\lambda)}{\partial z}\pm\frac{1}{v_g}\frac{\partial P^{\pm}_{sp}(\lambda)}{\partial t} = \left\{\frac{\Gamma g_l(N,\lambda)}{1+(\varepsilon_{ch}+\varepsilon_{shb})P_{tot}}-\alpha_{int}\right\}P^{\pm}_{sp}(\lambda)+\Gamma\frac{\beta_{sp}}{2}BN^2\hbar\omega_\lambda wd$$

And to complete the model we have the carrier rate equation:

$$\frac{\partial N}{\partial t}=\frac{I}{qV}-R(N)-\sum_{i=d,c}\frac{1}{\hbar\omega_{\lambda_i}wd}\frac{\Gamma g_l(N,\lambda_i)P_i}{1+(\varepsilon_{ch}+\varepsilon_{shb})P_{tot}}-\sum_{\lambda}\frac{1}{\hbar\omega_\lambda wd}\frac{\Gamma g_l(N,\lambda)(P^{+}_{sp}(\lambda)+P^{-}_{sp}(\lambda))}{1+(\varepsilon_{ch}+\varepsilon_{shb})P_{tot}}$$

With this model we have simulated pump-probe experiments realized on MZI-SOA's with 1ps sech^2 pulses at 1530 nm wavelength. The simulated and the experimental gating windows conform quite accurately (see figure).



Simulated (sim) and experimental (exp) outputs $P_=$ and P_x of optically controlled MZI-SOA switch.

Fabrication of All Optical Switches

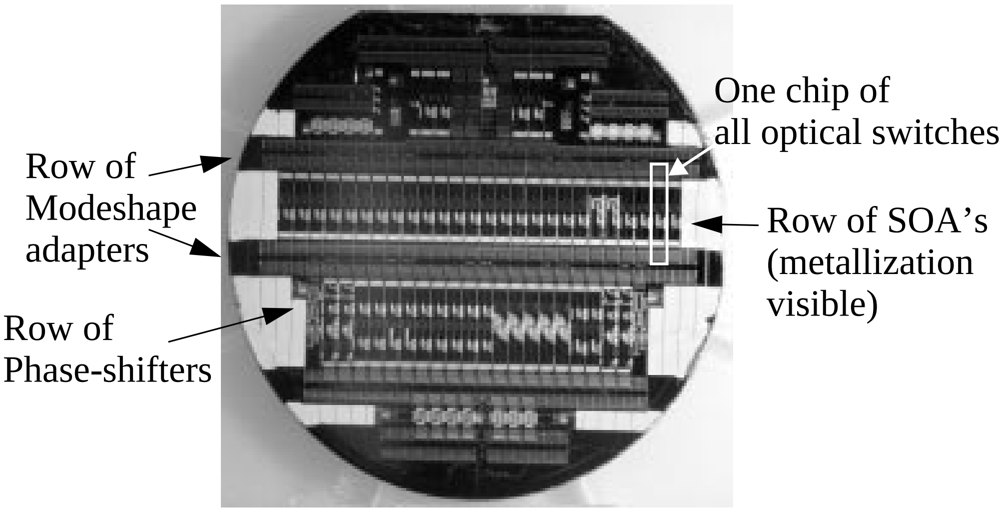
E. Gamper, W. Vogt, E. Gini

All optical switches (AOS) are key components in optical networks and high speed interconnections. Major applications for these components are optical demultiplexing of high bitrate signals with Add-Drop function and wavelength conversion for wavelength division multiplex (WDM) networks.

We fabricated monolithic integrated all-optical switches in a Mach-Zehnder configuration, based on InP using our inhouse technology. Components as semiconductor optical amplifiers (SOA’s), phase-shifters, waveguides, multimode-interference couplers (MMI) and mode shape adapters for stable passive mounting were integrated.

In a first step, all active components like SOA’s and phase-shifters were grown using metal organic chemical vapor deposition (MOCVD). They were structured using wet chemical etching. Then, all the passive components like waveguides, MMI’s and modeshape adapters were grown and structured using different steps of wet and dry etching techniques. Photodefinable benzocyclobutene (BCB) was used as insulation and dielectric layer before evaporation and electroplating the electrical contacts.

The figure below shows an InP-wafer after finishing of processing. The wafer will now be cleaved, anti-reflection coated and flip-chip mounted on a silicon motherboard, where fibers for coupling to the chip will be attached. This allows simple and stable interconnections to other optical components and the rest of the optical network.



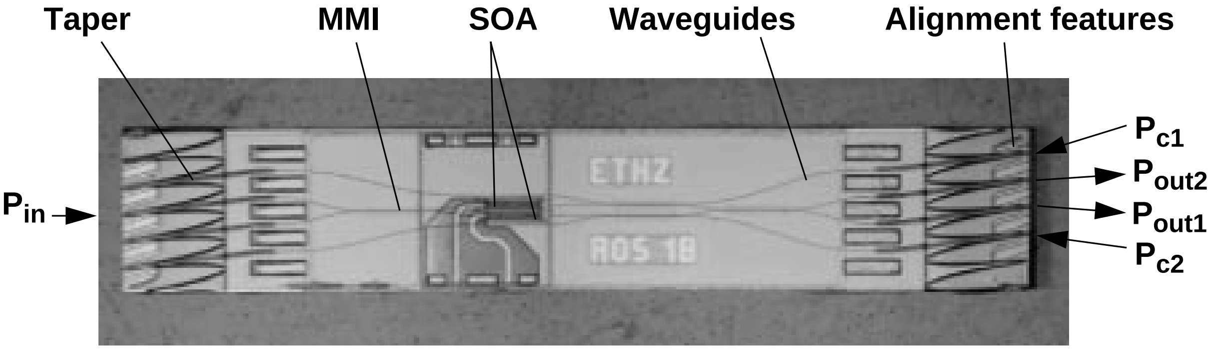
The figure shows a 2-inch InP-wafer featuring multiple chips of all-optical switches after finishing of processing. Modeshape adapters, metallization of semiconductor optical amplifiers (SOA’s) and phase-shifters are visible.

Principle of Flip-Chip-Mounted All-Optical-Switches

W. Vogt, E. Gamper

High-speed all-optical-switches using group III-V semiconductors will play an important role in optical communication systems. The all-optical-switches consist of semiconductor optical amplifiers (SOA), phaseshifters and multimode interference couplers (MMI) that are used as 3 dB splitters and combiners in a Mach Zehnder interferometer (MZI) configuration. For easing coupling of the optical signal to butt fibers and for enhancing alignment tolerances, mode shape adapters (tapers) are integrated on the devices. A flip-chip packaging technique that combines self-aligned optical array coupling between waveguides and single-mode fibers (SMF) and electronic interconnection has been developed.

The switching in these devices makes use of the nonlinear optical properties of semiconductor amplifiers. Introducing a short control pulse P_{c1} (~ 10 ps) into one arm of the MZI results in a dynamic change in the carrier population that is limited in speed by the carrier lifetime. The change in population leads to a change of the refractive index in this section of the MZI and, hence, due to the change of the phase, the optical signal is switched from output P_{out1} to P_{out2}. As soon as the additional carriers have recombined (which in comparison to the length of the control pulse is a relatively slow process), the refractive index change is cancelled, i.e. the signal is switched back to the original output. The switching speed is improved by introducing a second control pulse P_{c2} (several tens of ps later than the first) into the second arm oft MZI which results again in a change of refractive index. Even though the photogenerated carries in the first arm of the MZI are still producing a index change, the carriers in the second arm produce almost the same index change, i. e. the signal in the first arm and the one in the second have the same phase which makes the light come out at the original output.



All-optical switch consisting of semiconductor optical amplifiers (SOA), 3 dB splitters / combiners (MMI), waveguides and modeshape adapters (tapers).

Cascadable MZI All-Optical Switch with a Data- and Control-Signal Separation Scheme

J. Leuthold, P.A. Besse, E. Gamper, M. Dülk, W. Vogt and H. Melchior

All-optically controlled devices in compact monolithically integrated Mach-Zehnder interferometer configurations with semiconductor optical amplifiers (SOAs) on their arms, have already performed impressive switching speeds.

We have realized new types of all-optical devices that allow to separate the control and data signal after signal processing. These new devices allow operation in the fast copropagating operation mode (control and data signal propagate in the same direction) without additional external wavelength filters for control signal separation at the output. This is advantageous, since external filters introduce losses, modify the pulse form of short signals, lack of integration and increase costs.

The configuration allowing control- and data-signal separation (Fig.) uses 4 SOAs (SOA1 to 4). These form three MZIs: an exterior-MZI (1:2 - 3:4) with two additional MZIs (1 - 2) and (3 - 4) on each arm of the exterior MZI. A π phase shift, inserted either in the upper or the lower branch of the additional MZIs on the arm (1 - 2) and (3 - 4), respectively, guarantees that both the control (P_{C1} and P_{C2}) and the input-signal (P_{in}) are mapped into their respective bar output ports. A signal P_{in} is mapped into the cross output P_X when none of the control signals P_{C1} and P_{C2} are applied. When control signals are applied, the input-signal P_{in} is directed from the cross into the bar output $P_=$. The data and control signals propagate together through the SOAs, but before and behind the MMI couplers they are separated. Crosstalk in undesired channels is below -24 dB.

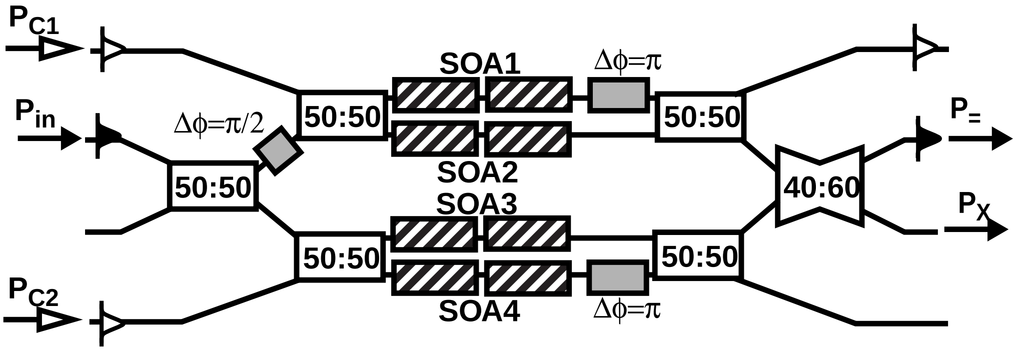


Fig. Interleaved MZI all-optical device, with a mode-separation scheme between input and control signal based on the integration of additional MZIs. These additional MZIs (formed by SOA 1-2 and SOA 3-4) are placed on the arms of the exterior MZI. The phases are adapted to map the control signal and the data signal to their respective bar outputs.

Analysis of Electro-Optic Effects in InP / InGaAsP Based Waveguide Structures

G. Hagn

Electrically controlled optical space switches are key components for use in practical optical communication networks, where they can perform fast switching, rerouting and channel add-drop functions. We chose to analyse InP/InGaAsP base Mach-Zehnder interferometer type switches because they are suitable for fast switching, have low losses and can be monolithically integrated with other electro-optic components. In order to control the characteristics of electro-optic switches we analysed the different electro-optic effects.

To analyse the electro-optic effects we fabricated integrated waveguide Mach-Zehnder interferometers. The phase shifting arms are implemented as pin-diodes and oriented under different angles with respect to the crystal axis. By reverse biasing the pin-diodes an electrical field is applied to the light conducting layer changing its refractive index. The refractive index change can be determined by measuring the light intensity modulation at the output of the Mach-Zehnder interferometer.

The major effects in our case are the Franz-Keldysh effect, the Pockels effect and the carrier depletion effect. We separated the Pockels effect from the other effects by using the fact that the Pockels effect affects only the TE polarisation in (100) InP/InGaAsP and has a $\cos(2\phi)$ dependency with respect to the $[0\bar{1}1]$ axis. The coefficients of the electro-optical effects were obtained by fitting the overlap integrals of the electric field with the optical mode into the measured refractive index change.

We are currently refining the analysis and comparing the results to expectations from quantum mechanical and oscillator models.

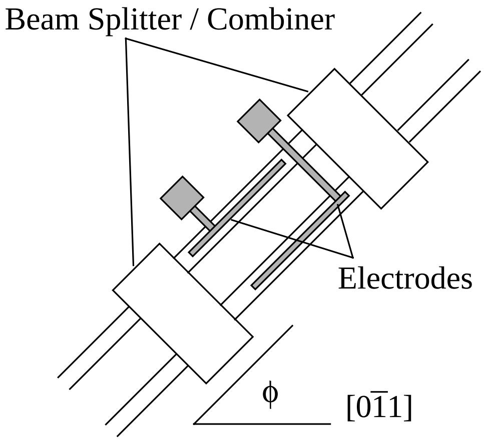


Figure 1: Schematic layout of a Mach-Zehnder interferometer

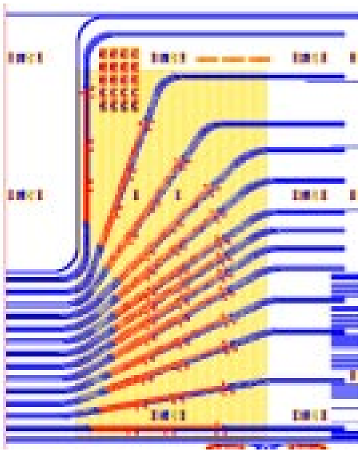
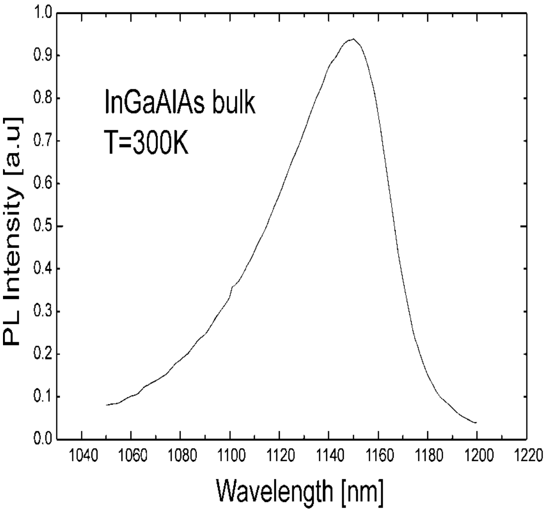


Figure 2: Layout of the chip featuring Mach-Zehnder interferometers oriented at different angles with respect to the $[0\bar{1}1]$ axis

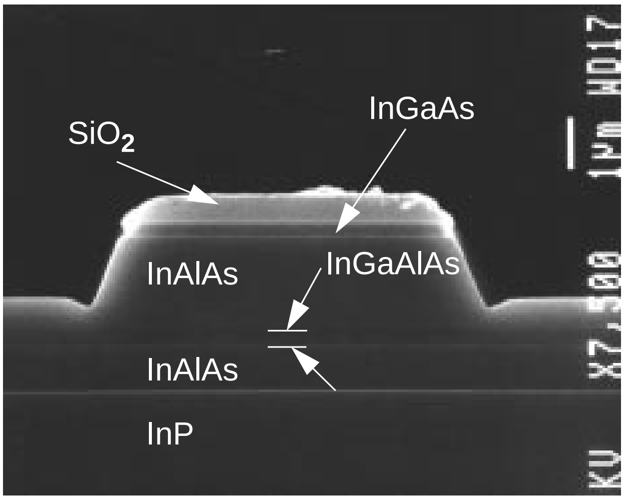
Low loss waveguides based on InAlAs/InP

L. Alimkulova, E. Gini and H. Melchior

We have developed processes for the growth of planar InGaAlAs, InAlAs and InGaAs layers lattice matched to InP by metal organic vapor phase epitaxy (MOVPE). We realized high quality layers and optical waveguides with losses lower than 2dB/cm. InAlAs is used as a barrier and InGaAlAs as a well in the multiquantum well structure. This heterostructure was chosen mainly because of the sharp interface, material quality, and high conduction-band offset. The bandgap energy of bulk InGaAlAs was adjusted to1.1 eV. The light is confined in the waveguide core (370 nm thick InGaAlAs layer), sandwiched between InAlAs upper and InAlAs lower cladding layers. The 1700nm thick InAlAs upper cladding layer was added to minimize radiation losses, and an InGaAs layer was deposited to protect it against oxidation. For the fabrication of waveguides, an SiO2 layer was deposited by plasma enhanced chemical vapour deposition (PECVD), which was used as a mask. Then 1 .. 7 µm wide and 1.5 µm deep ridge waveguides were defined by standard photolithography and Ar/CH4/H2 reactive ion etching.



Room-temperature photoluminescence spectrum of a bulk InGaAlAs layer



SEM cross-sectional view of an optical waveguide

The waveguides were measured by end-fire coupling a mode locked Fabry-Perot laser (1.53 µm). The input beam was TE or TM polarized and the average power measured at waveguide exit was imaged with an IR camera. The waveguide facets have been AR coated during the manufacturing process.

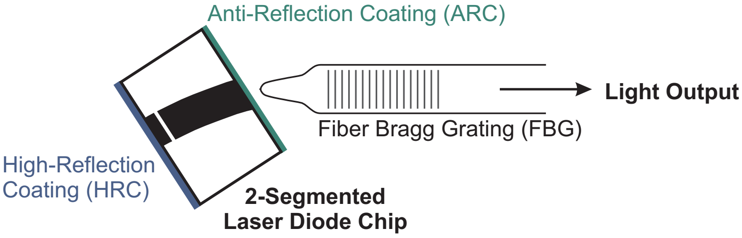
High Bit Rate Optical Pulse Sources

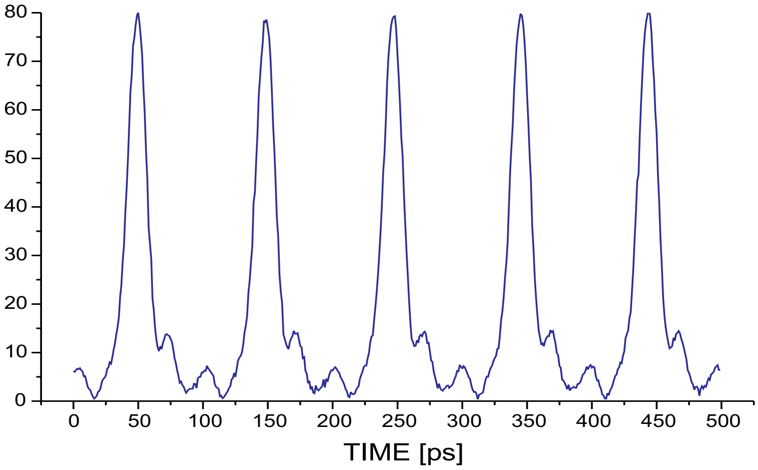
M. Dülk

Optical pulse sources are key components for optical telecommunication purposes like data generation, transmission and regeneration. In combination with an optical gate (modulator), optical data streams with return-to-zero (RZ) format can be generated, usually at bit rates of 10 Gbit/s. The optical pulse source generates a RZ pulse train with a repetition rate of 10 GHz that is actively controlled and can thus be synchronized. Requested pulse duration for most applications is about 15-20 ps FWHM for a 10 GHz optical pulse source. Reducing the pulse duration down to 5 or 1 ps FWHM, the 10 GHz or 10 Gbit/s signal can be multiplexed to 40 or 160 Gbit/s, respectively, for high bit rate experiments.

One approach to realize such an optical pulse source is active or hybrid mode-locking. Here, the cavity length of the laser is adjusted so that the longitudinal mode spacing equals the external modulation frequency of 10 GHz. Semiconductor lasers offer good modulation characteristics but are usually very short, resulting in a large longitudinal mode spacing, typically several hundreds GHz. Thus, for active mode-locking the laser is extended, for instance by means of fibre Bragg gratings, to form an external cavity laser. External cavity lasers incorporating a fibre Bragg grating with a total length of about 10 mm have been realized to produce mode-locked laser pulses of 12 to 20 ps at repetition rates of 10 GHz.

Scheme of an external cavity laser incorporating a fibre Bragg grating. The semiconductor laser chip is provided with a high- and anti-reflection coating for coupling to an external grating.





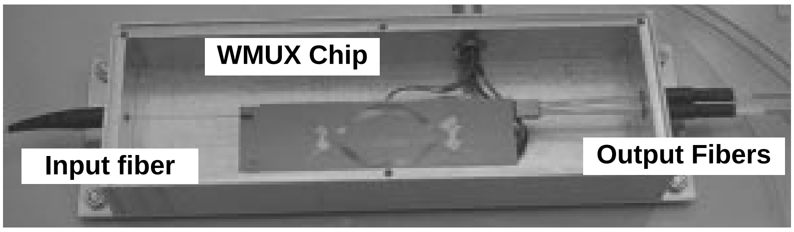
Train of mode-locked pulses of 15 ps at a repetition rate of 10.0 GHz, obtained with external cavity laser shown above.

Wavelength Multiplexer Modules in Glass on Silicon

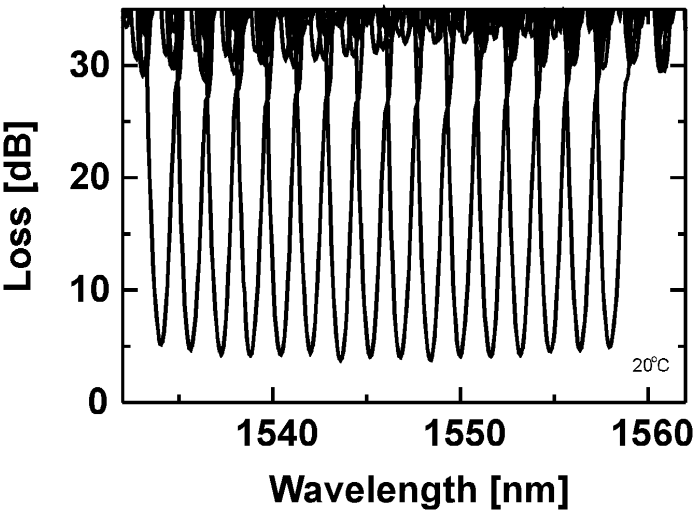
Ch. Nadler, W. Hunziker, E. Wildermuth and M. Lanker

Wavelength division multiplexing (WDM) offers full exploitation of the almost unlimited bandwidths of optical fibers. Key elements of WDM are wavelength multiplexers (WMUX's).

For an optical packet switching and routing network we used the arrayed waveguide grating (AWG) concept and the silica on silicon technology to realize WMUX's. This allows for low-loss, low-crosstalk, exact channel allocation, and long term stability. A penalty-free birefringence compensation method using stress release grooves reduces the fabrication induced strain birefringence.



Fully packaged 16 channel wavelength multiplexer module with opened case and measured performance data.



ν_{ITU} [THz]	ν_{20} [THz]	$\nu_{extr. 50}$ [THz]
195.30	195.36	195.31
195.10	195.16	195.11
...	...	...
193.50	193.55	193.50
193.30	193.35	193.30
193.10	*193.15*	*193.10*
192.90	192.95	192.90
192.70	192.75	192.70
192.50	192.55	192.51
192.30	192.36	192.31

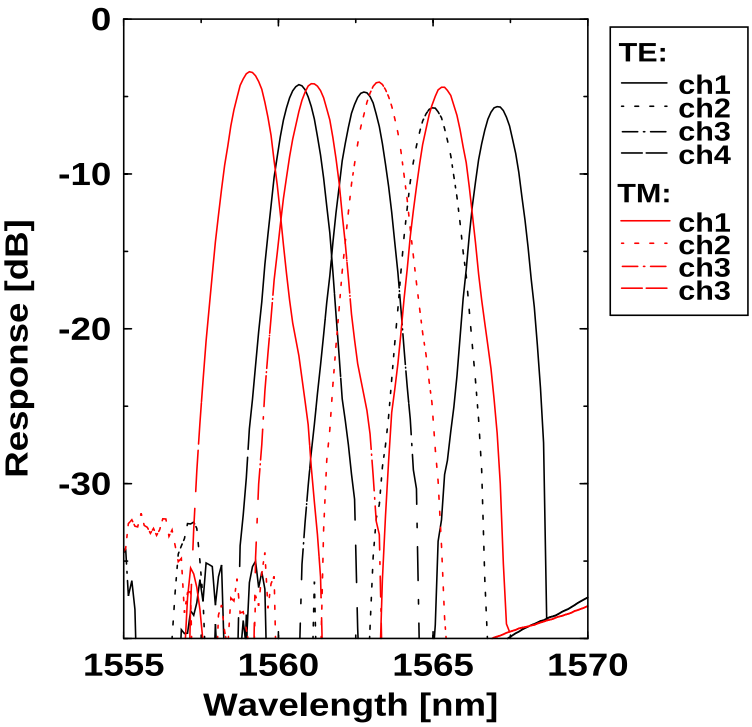
Number of Channels:	**16**	**3 dB Filter bandwidth:**	**0.5 nm**
Material and Index Contrast:	**SiO_2/Si , 0.7%**	**Chip Size:**	**70 mm x 23 mm**
Center Frequency:	**193.75 THz (1547.4 nm)**	**Polarization shift:**	**< 0.04 nm**
Channel Spacing:	**200 GHz (1.60 nm)**	**Polarization penalty:**	**< 0.2 dB**
Fiber-to-Fiber-Insertion Loss:	**< 5.2 dB**	**Temperature dependence:**	**1.25 GHz/°C**
Optical Crosstalk:	**< -25 dB**	**ITU Grid reached at:**	**50°C**
Free Spectral Range:	**> 27 nm**	**Transmission measured at:**	**20°C**

Fabrication of Phased Array Filters in InP Buried Multi-Quantum-Well Waveguide Structures

M. Lanker

Phased Arrays are the standard devices for optical filtering in telecommunication. They are fabricated on material systems such as silica on silicon. We realize such filters on the InP / InGaAsP material system because it leads to more compact devices and offers the potential to be integrated with active optical elements, i.e. amplifiers, photodetectors as well as electronics.
Optical filters based on interferometry such as the phased array filter are dependent to the effective refractive index of the used waveguides. Usually, the refractive index of a waveguide is not equal for both TE and TM polarizations. In most cases, polarization insensitive devices are wanted. The buried waveguide offers the possibility to have zero-birefringent waveguides because its geometry can be symmectric for both polarizations.
A high index contrast between core and cladding leads to very small structures and optical modes. We optimized the buried structure using a small refractive index contrast. To obtain this, we use a diluted quantum well layer which has a lower effective refractive index. The added horizontal layers cause an intrinsic birefringence in the waveguide, which has to be compensated for by tensile strain in the future.

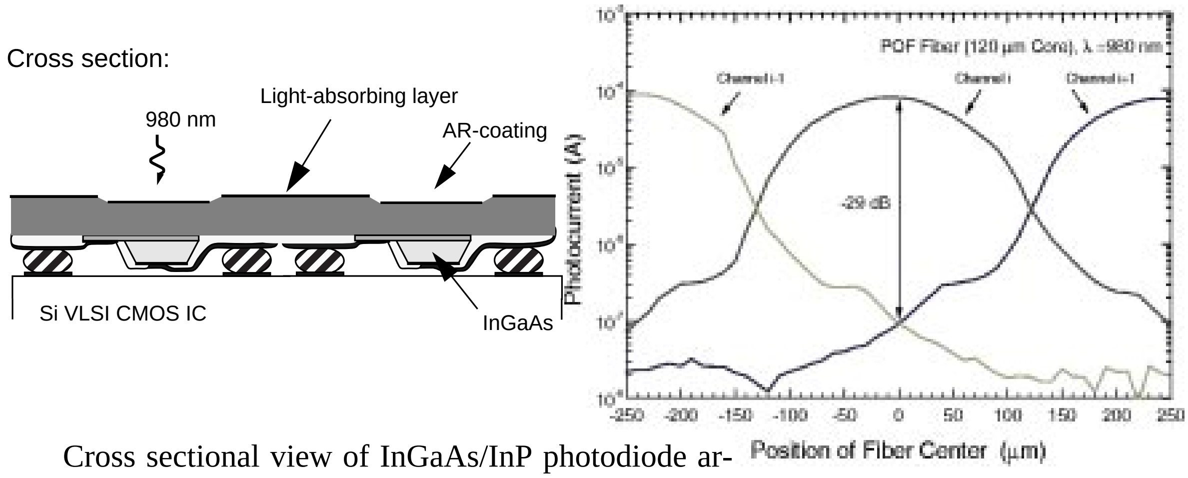
Response of a four-channel Phased Array Filter for TE and TM polarisation compared to a straight waveguide.



InGaAs/InP Photodiode Arrays for Optical Interconnects

M. Blaser

The target of this project is to develop a two-dimensional, back-illuminated InGaAs/InP photodiode array, that can be flip-chip mounted on silicon VLSI chips. Optical interconnects offer the possibility to remove the electronic interconnect bottleneck which arise from ever increasing IC complexity, speed and interconnect requirements. Two-dimensional flip-chip mounted InGaAs/InP photodiode arrays are key components for high-throughput optical intra- and inter-chip interconnects (as opposed to edge). In order to obtain an efficient, high speed optoelectronic interface between the silicon integrated VLSI electronics and optical fibres, InGaAs/InP pin photodiode arrays are developed that are flip-chip mounted on the silicon IC and that allow simultaneous illumination with a wavelength of 980 nm through the substrate. The scalable photodiode array chip consists of 4 x 8 back-illuminated photodiodes with the active regions on a 250 x 250 grid. In order to collect a maximum of the divergent light from the plastic optical fibre and to minimize crosstalk due to light coupled to neighbour photodiodes in the array, the light sensitive regions are made accessible through the back-side of the chip. Access openings are coated with an antireflection coating whereas the areas around them are coated with a light absorbing material. The optical crosstalk characteristics of this structure resulting from illumination through a plastic optical fiber with 120 µm core diameter to 980 nm light is shown below.



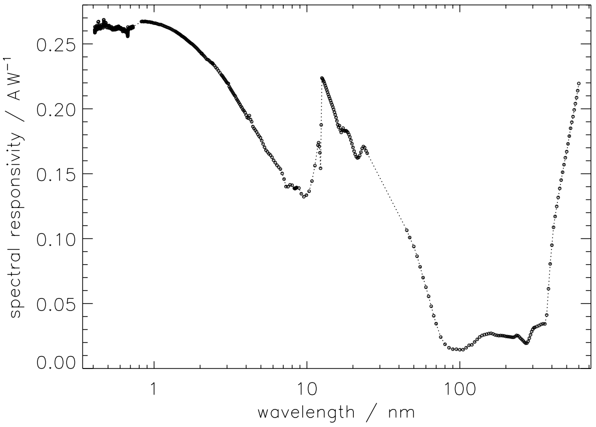
Cross sectional view of InGaAs/InP photodiode array and optical crosstalk characteristics recorded for

Large Area PtSi-nSi Photodetectors with Stable Spectral Responsivity in the UV to soft X-ray Spectral Range

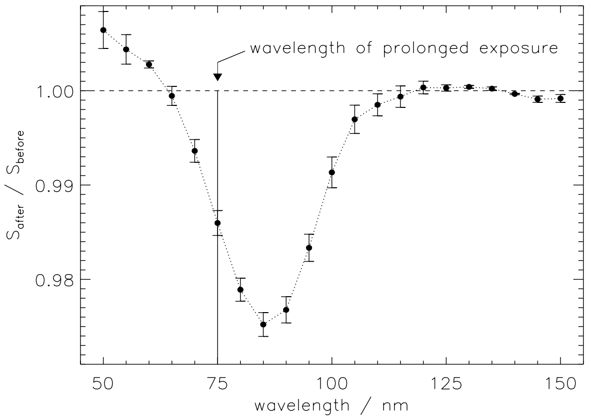
K. Solt, H. Melchior: Swiss Federal Institute of Technology, CH-8093 Zurich
H. Henneken, P. Kuschnerus, H. Rabus, F. Scholze M. Richter: Physikalisch Technische Bundesanstalt, Abbestrasse 2-12, D-10587 Berlin

Large area front-illuminated PtSi-nSi Schottky barrier photodiodes with improved silicide-silicon interface flatness have been developed for use as radiation standards in the ultraviolet (UV) and vacuum ultraviolet (VUV) spectral ranges. The optical characterization of these photodiodes were performed at the soft X-ray (SXR) and UV/VUV detector calibration facilities of the Physikalisch-Technische Bundesanstalt (PTB) and the crystal monochromator beamline (KMC) of the Berlin electron storage ring BESSY, respectively.

The absolute spectral responsivity of the PtSi-nSi photodiodes (Fig.1) was determined in the 0.5 nm to 500 nm wavelength range by comparison to a absolute radiometer [1]. The spectral responsivity proved to be stable under prolonged exposure to soft X-ray radiation as well as to VUV radiation, with the exception of the 40 nm to 80 nm wavelength range. The most pronounced radiation damage was encountered for the 75 nm wavelength, where a reduction of the spectral responsivity by about 2% was found after a radiant exposure of 0.8 mJ/mm^2 (Fig.2). This change in responsivity manifests itself only in a narrow wavelength range, and is by an order of magnitude lower than for the Si n-p or p-n, or GaAsP Schottky photodiodes in this wavelength region.



Spectral responsivity of a PtSi-n-Si Schottky photodiode as determined by reference to the primary detector standard SYRES, a cryogenic electrical substitution radiometer [1].



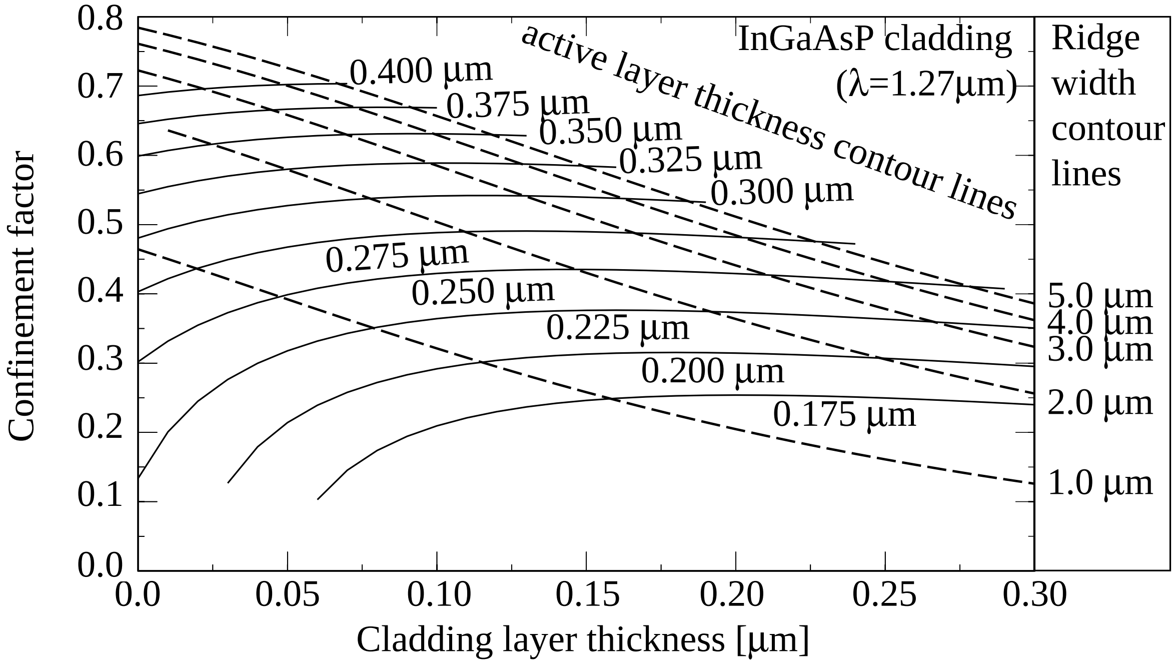
Change of the spectral responsivity of a PtSi-n-Si Schottky photodiode under prolonged exposure to 70 nm radiation.

[1] H. Rabus, V. Persch and G. Ulm, Appl. Optics **36** (1997) 5421-5440

Polarization Insensitive Semiconductor Optical Amplifiers at 1.55 µm Wavelength: Modeling, Fabrication and Integration

J. Eckner

Polarization insensitivity is a key issue for these ridge waveguide SOA’s. Successfull modeling using effective index method incorporating current effects in active SOA’s yielded the correct geometrical dimensions where these SOA’s exhibit polarization insensitive gain.
Fabrication of such SOA’s for the 1.55 µm wavelength region yielded amplifiers with as much as 28 dB chip gain with less than 1 dB gain imbalance, 47 nm bandwidth, 7.4 dBm saturation output power and an overall noise figure at gain peak of 11 dB.
Integration of these SOA’s with optical waveguides forming an 1x2 gate switch resulted in a switch with 20 dB chip gain, less than 1 dB polarization sensitivity in each arm and less than 1 dB gain imbalance between the arms.



Modeling of polarization insensitivity dependent on ridge width, cladding and active layer thickness. In the Y-Axes, for each of these structures the respective confinement factor is given.

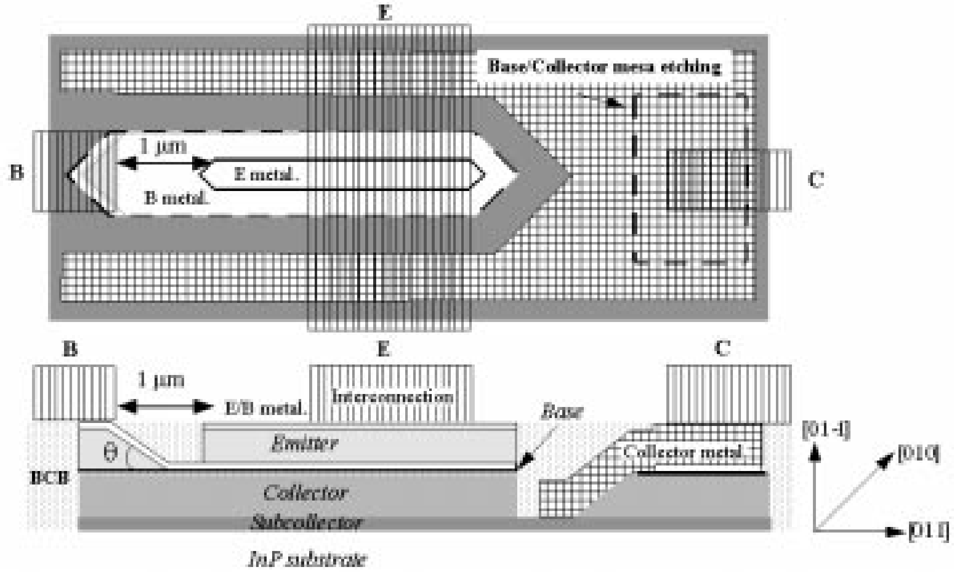
A New Concept for InP HBT Circuit Fabrication Technology

M. Le Pallec

Fabrication process and layout are of major importance for the realization of high-speed InP Heterojunction Bipolar Transistor-based integrated circuits. A high-performance HBT fabrication process using self-aligned techniques has already been demonstrated at IQE. One of this proven techniques - a self-aligned emitter-base metallization -takes avantage of wet chemical etching profiles in the [0 1 -1] crystal direction of InP and InGaAs.

A new submicron HBT-based fabrication process has been investigated by using this wet chemical etching know-how and by exploiting the noticeable planarization properties of BCB dielectric. One of the key steps of this technology relies on the connections at the same top level of all components by taking avantage of the smooth etching profile of InP and InGaAs in the [0 1 -1] crystal direction (θ=30˚). After spin-on and curing the BCB coating is etched back by RIE to reveal all contacts, prior to a thick metallization deposition. This technique enables an easy connection of the submicron emitter finger and a substantial reduction of the parasitic base-collector capacitance of the base metallization pad.

A fast fabrication process for HBT-based integrated circuits (6-7 masks) has been developed on this concept. Its applications include high-speed integrated circuits for optical communications over 40 Gbit/s, such as driver circuits and photoreceivers.



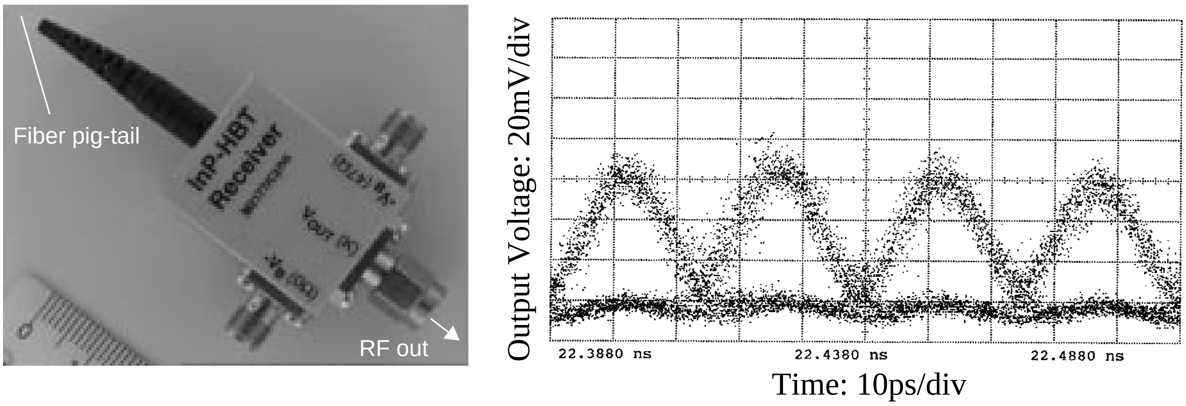
Lay-out and cross-sectional view in the [0 1 -1] crystal direction of the projected InP-HBT by exploiting the BCB planarization properties and the wet chemical etching profile direction dependency of InP and InGaAs.

Monolithically Integrated 40Gb/s pin/HBT Optical Receiver Module

M. Bitter, R. Bauknecht and W. Hunziker

For future 40Gb/s time-division multiplexed (TDM) fiber-optic transmission systems, high-speed baseband optical receivers are needed. The monolithic integration of optical receivers offers the advantages of high-speed performance, small size and possible cost reduction of packaging. Besides a suitable technology for the integration of photodiodes and transistors, a broadband mounting technique is crucial for the fabrication of optical receiver modules. For the realization of our optical receiver module we monolithically integrated top-illuminated pin photodiodes with single-heterojunction bipolar transistors (HBT) in the InP/InGaAs material system. The optical receiver circuit consists of a pin photodiode and a broadband darlington feedback amplifier. The optical receiver chip is connected to an alumina mounting substrate by wire bonding. On this mounting substrate, we integrated the necessary decoupling circuitry and bias network for the optical receiver chip. The optical receiver chip and alumina mounting substrate are built in a brass housing and furnished with connectors for the DC power supply and the RF output signal. A slant-ended single-mode fiber couples the incoming light into the top-illuminated pin photodiode.

At 1550nm wavelength, we measured an overall conversion gain of 48V/W, an optoelectronic small-signal bandwidth of 30GHz and clearly opened eyes for a 40Gb/s transmission experiment for our optical receiver module.



Photograph of optical receiver module (left) and measured eye-diagram obtained from a transmission experiment at 40Gb/s (right). The optical signal was an RZ coded PRBS with a sequence length of 2^{31}-1 and input optical mean power of -1dBm at a wavelength of 1550nm.

Electronic High-Speed, High-Current Driver Circuit

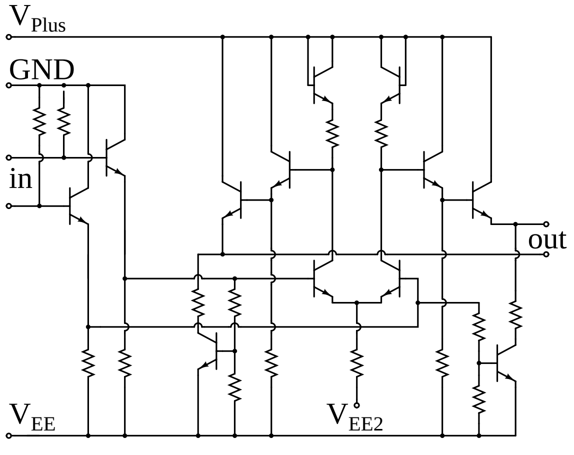
H. Schneibel, R. Bauknecht, and C. Graf

Future telecommunication networks request electronic driver circuits capable to work with 10 Gbit/s and faster to control active elements as laser diodes and semiconductor optical amplifiers (SOA’s).

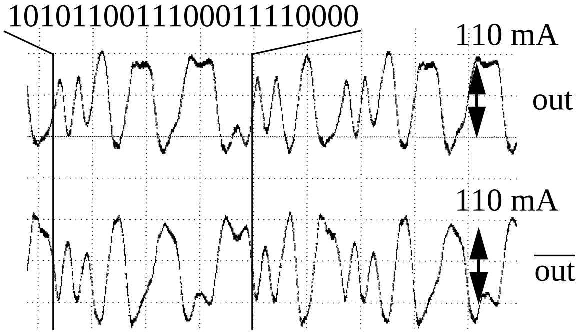
This driver circuit implements a new designed output stage, which allows very precise control of output current for loads of 8.3 ohm as well as for SOA-gates. Open collector output stages realized in former circuits showed ringing as a problem that could be significantly reduced with this new output stage. 12 Gbit/s with output current of 110 mA is the maximum operating frequency.

Inputs are ECL compliant with 50 ohm on-chip termination resistor. Thus standard ECL electronics is a suitable signal source. Signals are connected by 50 ohm coaxial cables and coplanar transmission lines on a substrate to the device under test. For measurements a 10 ohm load resistor is bonded next to the circuit in parallel to the output pads. Output signals are sampled with a 50 ohm oscilloscope resulting in a total of 8.3 ohm load resistance.

Power consumption reaches 2.4 W dissipated in the circuit and two times 0.4 W dissipated in the load resistors for the maximum output current of 160 mA shown below at a data rate of 3 Gbit/s.



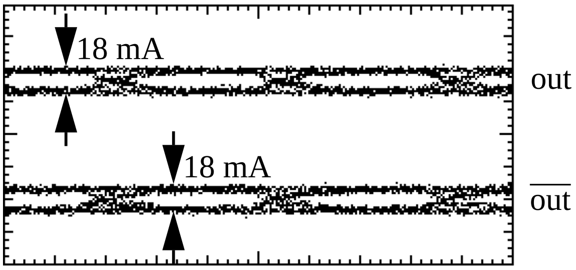
Circuit schematics



60 mA/div; 500 ps/div

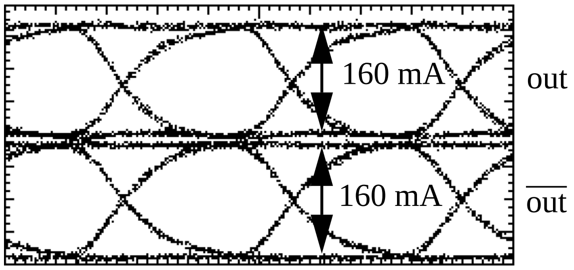
101011001... bit sequence at 12 Gbit/s

Load: 8.3 ohm resistor



24 mA/div; 100 ps/div; 8.3 ohm load

Pseudo random bit sequence at 3 Gbit/s



48 mA/div; 100 ps/div; 8.3 ohm load

Pseudo random bit sequence at 3 Gbit/s

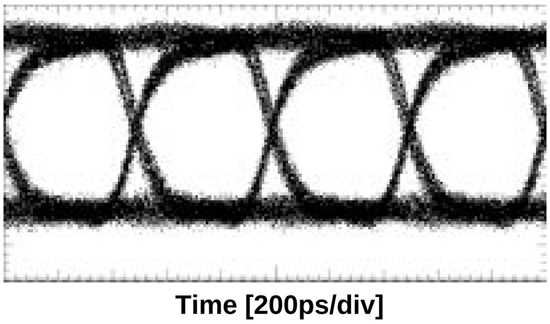
Laser Driver Circuits Implemented in CMOS Technology

Richard Annen, Jörg Wieland

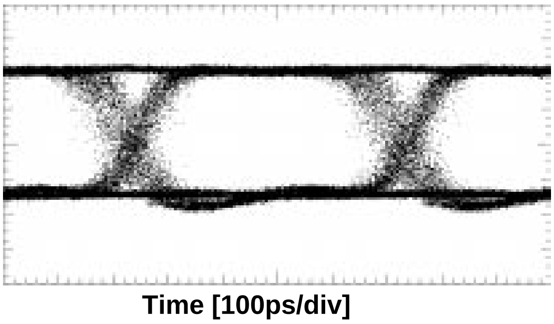
Optical links employing vertical-cavity-surface-emitting-lasers (VCSEL) constitute a promising solution to the interconnect bottleneck of future VLSI and MCM designs. They provide high bandwidth at low cross-talk even when densely spaced. For low cost, driver and receiver circuits need to be integrated together with VLSI circuitry in standard CMOS technology.

In several European projects (ESPRIT, RODCI, OIIC) demonstrator chips and modules have been developed to prove the optical data transmission and clock distribution concept. For these modules we designed and implemented driver chips in a 0.6µm CMOS technology optimized for high data rates up to 2 Gbit/s while keeping power consumption and noise injection to a minimum.

We measured the performance of driver chips in electrical and optical measurement setups. In figure a) the electrical output signal of driver when driving 50 Ohm load is shown. High speed operation up to 2Gbit/s with clear open eye can be measured. Rise- and falltime are below 150ps. In figure b) the output signal of receiver detecting optical signal of transmitter in a free-space measurement setup is shown. Operating speed up to 2Gbit/s is demonstrated.



a) eye-diagram of driver chip output signal if loaded with 50 Ohm resistor (50mV/div). The electrical input signal is NRZ, 2Gbit/s, PRBS 2^{31}-1.



b) eye-diagram of receiver output signal detecting optical signal (NRZ, 2Gbit/s, PRBS 2^{31}-1) emitted by Honeywell VCSEL when driven with driver chip.

Receivers for Optical Interconnects

A. Schmid

The increasing amounts of data generated by new emerging multimedia and information technology services must be transported between and within racks, boards and integrated circuits of electronic systems. Serial and parallel optical interconnects are capable of handling this vast amount of data. Reasons for considering parallel optical interconnects include, low latency, minimal delays and skew, simplified and less power consuming electronics and compactness.

In the frame of several European research projects, such as OIIC and COBNET, our group has developed AC-coupled parallel receiver arrays in commercial CMOS and BiCMOS technologies with aggregate line-bitrates above 10Gbit/s. Main challenges in the design of these receiver arrays have been crosstalk suppression, receiver sensitivity and low power dissipation. The CMOS receivers are suited for short distance interconnects between and within CMOS VLSI ICs. The BiCMOS receivers aim at medium distance interconnects between boards and racks. The receivers have been implemented with success in the system demonstrators of these projects and show that parallel optical interconnects are an attractive solution to overcome the bottlenecks of their electrical counterparts. The sensitivity for the CMOS receivers is -23.6dBm at a bitrate of 150Mbit/s with a detector responsivity of 1A/W and a detector capacitance of 2pF. The sensitivity for the BiCMOS receiver is -26dBm at a bitrate of 1.06Gbit/s with a detector responsivity of 0.8A/W and a detector capacitance of 0.5pF.

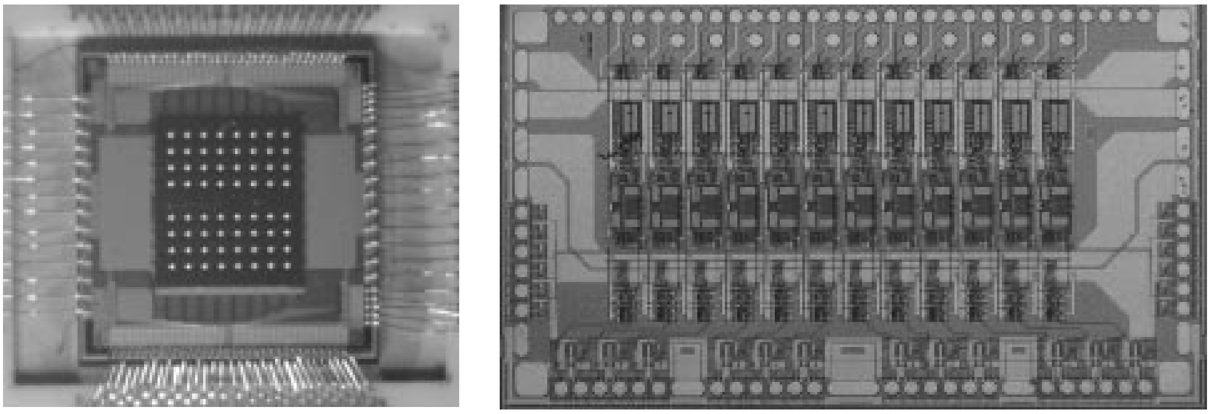


Figure: Left: OIIC 8x8 CMOS receiver array with flip-chip mounted detectors bonded onto a ceramic substrate for operation up to 150Mbit/s/cannel.
Right: COBNET 12-channel BiCMOS receiver array IC for operation up to 1.06Gbit/s/channel.

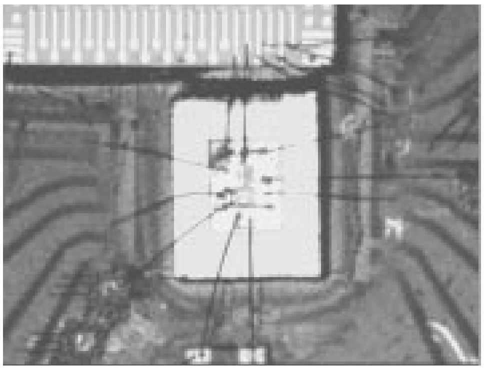
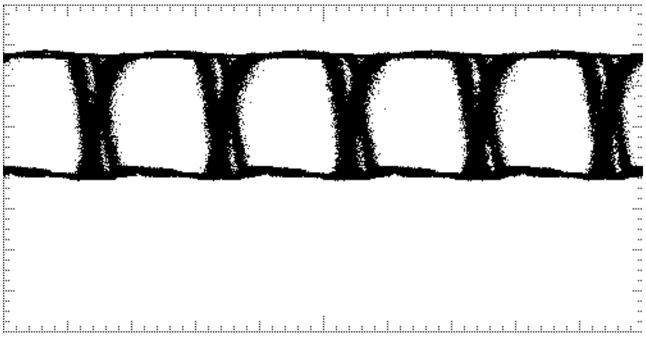
CMOS Receiver Circuits for Optical Interconnects

Patrick Zenklusen

Optical interconnects combining parallel optical paths consisting of transmitter-, optical fiber or waveguide- and receiver-arrays are of interest for high throughput interconnections between electronic systems.

For such interconnects, an electronic receiver circuits is being developed. The circuit is being developed for high performances in terms of datarates and input sensitivity.

A set of receiver circuit is being developed. The test circuit works up to 1Gbit/s. The integrated circuits have been fabricated on a commercial 0.6µm CMOS technology. The supply voltage for the circuit is 3.3V. Special care has been taken in the design to improve the sensitivity and datarate.

	Measurement setup with test chip containing a 12 photodiode array. The receiver is fabricated in 0.6µm CMOS. The optical signal is being amplified and digitalized on chip.
	Eye-diagram of transmitter demonstrator at 1000 Mbit/s; Supply voltage 3.3V; Sensitivity = 14uApp; Clock pattern; Persistance = 2 Min. Scale: 0.5ns/div; 80mV/div

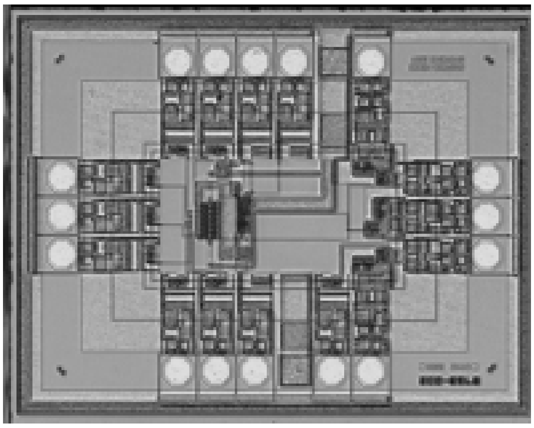
Phase and Frequency Locked Multiphase Electronic Oscillator

M. Bossard, J. Schmid

A switchless communication network pursued by the EU project SONATA needs optical receivers allowing non-continous (burst-mode) data transmission.For a efficient communication these receivers must be able to synchronize within a few bits to a incoming data-burst. In this context a test-chip was developed containing a PLL circuit to produces several different equidistant phases with low jitter of a plesiochronous clock reference. The chip was realized in a CMOS technology.

Compared with most other phase locked loop designs, the choice of voltage controlled oscillators was restricted to ring oscillators having multiple output points. An inverting n-channel transistor was chosen as the basic inverter cell of this ring. Each of these transistors is supplied by a current source with a common voltage control. The signal of each inverter is amplified to be output with full voltage swing.

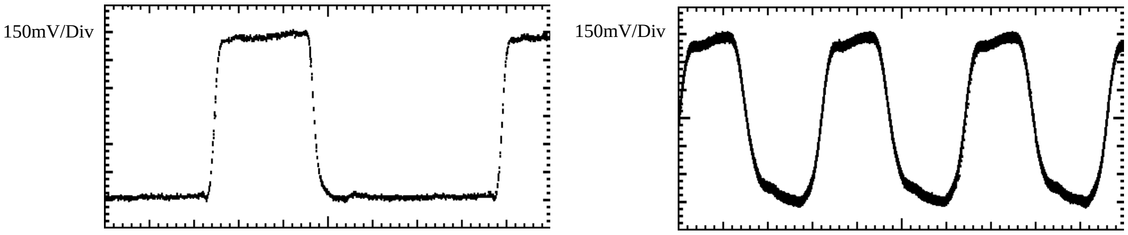
Simple phase locked loops can lock on multiples of a reference frequency. Since an external limitation of the capture range was not foreseen, we had to implement a phase and frequency comparator. The behavior of such a circuit differs in another point from classical PLLs: The capture range is equal to the tracking range, and it does not depend any more on the loop filter characteristics.



left: Photograph of the CMOS die

bottom right: One of seven output signals at 627MHz

bottom left: One of seven output signals at 155MHz



The circuit can capture and track a reference frequency within a range of 40 MHz to 810 MHz. Outputs are open drain n-channel transistors loaded with 50 Ohms external pull-up resistors for the test measurements.

Silicon Integrated Circuits for System Testing

C.Graf, G.Tamburello

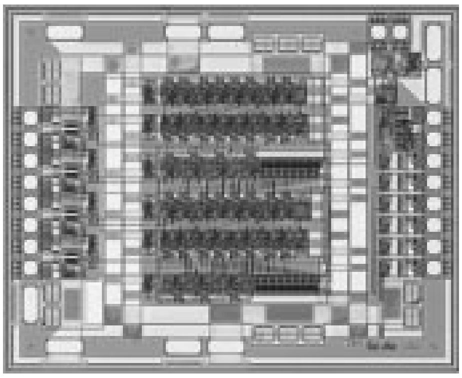
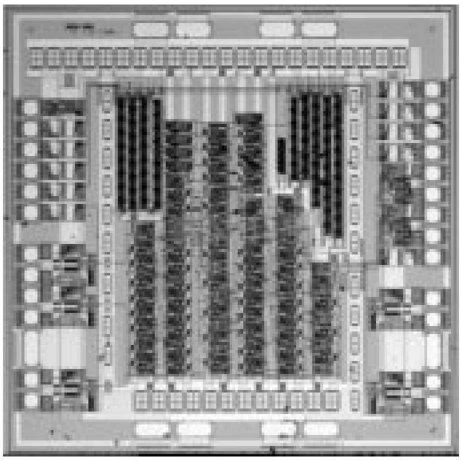
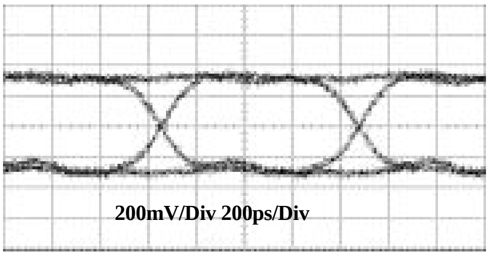
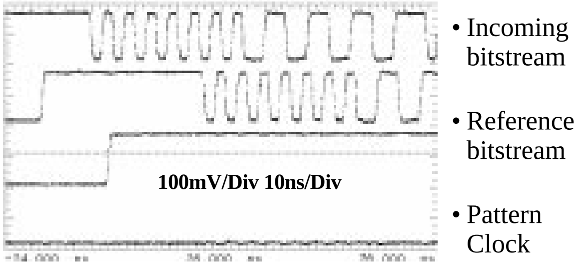
Broadband optical fiber communication systems need high performance frontend circuits (Receivers/Transmitters). Such Si-frontend circuits are developed in our group. For testing these frontend circuits two test chips have been developed. With these test chips it is possible to realize a low cost test equipment.

One testchip (TX) is a pseudo random bit sequence generator which generates bit sequences of 2^{15} -1 bits with bitrates from 600Mbit/s to 1.5Gbit/s. The clock source is an onchip tuneable oscillator.

The other test chip (RX) provides bit error measurement. It compares the incoming bitstream with an onchip generated 2^{15} -1 pseudo random bit sequence and counts the received bits and the errors. Errors occure when incoming and reference bitstream are different.

This two values can be readout by a SPI (serial peripheral interface) interface to further process e.g. in a microcontroller.

Both chips have differential ECL inputs and outputs. The supply voltage can vary in a range from 3.3V to 5V. They are fabricated in a 0.8um BiCMOS Process.

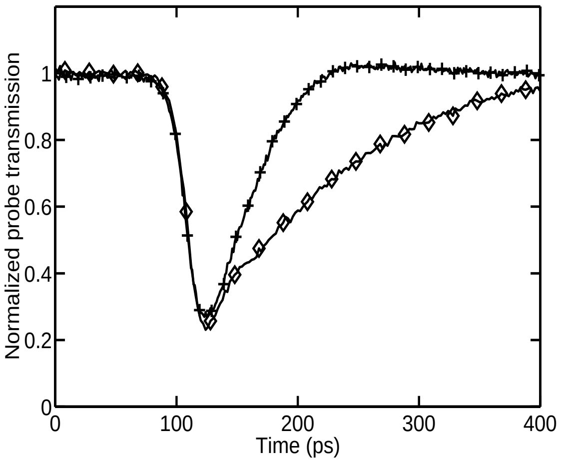
	
2^{15}-1 PRBS Generator, TX	Chip for support of BER-measurment, RX
 	
Output signal of ECL outp. at 1.22Gbit/s	Incoming and reference bitstream of RX

Digital Optical Fibre Logic Modules

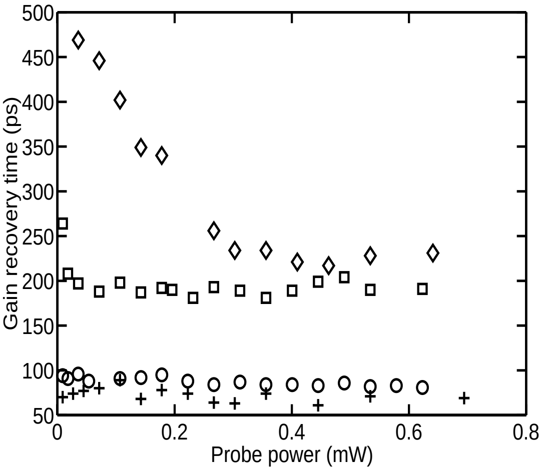
L. Occhi, F. Girardin, G. Guekos

All-optical logic and processing of information has a vast application potential in telecommunications and high-speed signal processing. The exploration of a suitable technology platform to build and exploit the possibilities of using all-optical, digital logic circuits for data processing at rates potentially in excess of those than electronic circuits are capable of is a promising approach towards the optically transparent fibre networks and associated diagnostic instrumentation.

In co-operation with European partners we are investigating the performance of the Sagnac interferometer incorporating semiconductor optical amplifiers (SOAs) for wavelengths around 1550 nm as building blocks for all-optical logic operations. We have demonstrated the feasibility to construct Sagnac logic gates with switching energy as low as 10 fJ, latency as low as 13 ns, and have tested the Boolean functionality AND, NOT and XOR up to 10 GHz. Since the SOA is the key element in the Sagnac interferometer, we have tested the gain recovery dynamics of the device and found how they depend on device length and optical signal intensity by comparing modeling and experimental results. We are now proceeding with the implementation of gate cascadability and frequency up-gradability to 20 GHz.



Typical probe transmission curves for 500 µm (◊) and 1500 µm (+) long SOA devices



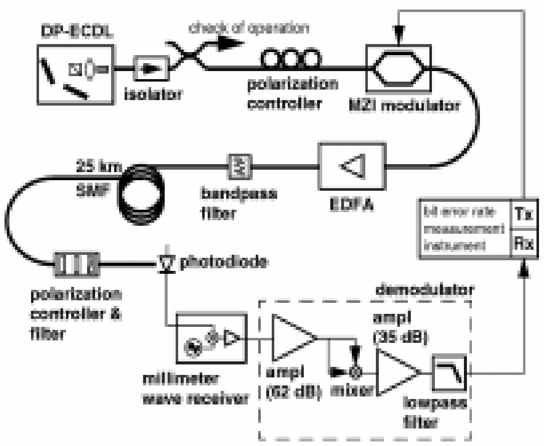
Measured 10%-90% gain recovery time for four different SOA lengths as a function of the input power. 500 µm (◊); 750 µm (❑); 1000 µm (o); and 1500 µm (+).

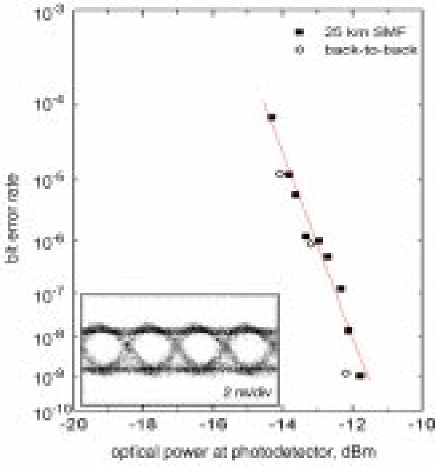
Microwave Photonics Using an External Cavity Diode Laser

S. Pajarola, G. Guekos

Employing optical signals through fibres for antenna remote feeding in future mobile broad-band communications systems is gaining increased interest because of the obvious advantages offered by the combination of fibre optics and millimeter-wave techniques. In pico-cellular systems the cost of the numerous base stations can be kept low by generating, distributing and controlling the millimeter-waves from a central station to the base stations through fibres.

We have designed and realised a laboratory version of a novel, flexible and simple optical millimeter-wave transmitter that is based on the photomixing of two optical frequencies emitted from a specially developed dual-polarisation, wavelength tunable external cavity diode laser in the wavelength range around 1550 nm. This scheme uses also the intrinsic properties of commercial electro-optic modulators that select only one of the polarisations for modulation and leave the other unaffected. We have demonstrated successful transmission over 25 km of standard single-mode fibre of 200 Mbit/s signals by binary amplitude shift keying (BASK) using a 58 GHz carrier which results from the beating of the two optical modes.





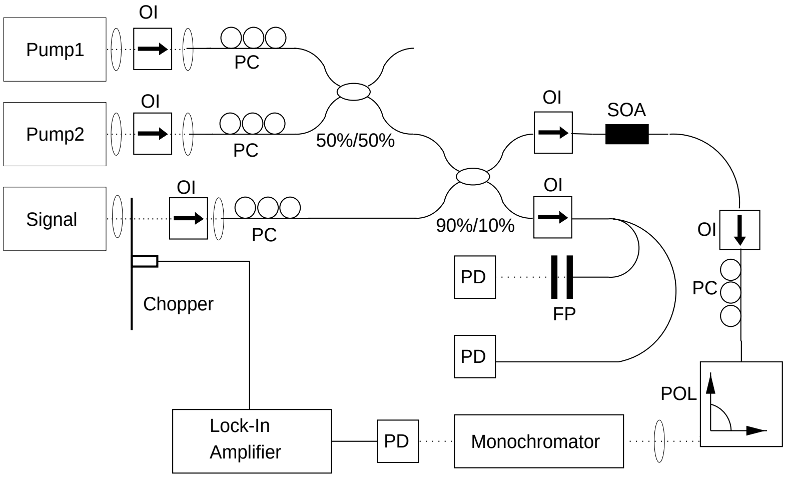
Semiconductor Optical Amplifiers in Four-Wave Mixing System Experiments

F. Girardin, L. Occhi, G. Guekos

Semiconductor Optical Amplifiers (SOAs) designed and fabricated in our group, exhibiting high fibre-to-fibre optical gain around 25 dB, polarisation sensitivity less than 2 dB, and having different lengths, were implemented in several fibre-optic transmission system experiments that make use of the Four-Wave Mixing (FWM) effect, in collaboration with research groups at the Fondazione Ugo Bordoni, Rome, the California Institute of Technology, Pasadena, and the company Opto Speed SA in Mezzovico, Ticino. Purpose of the experiments was to prove the suitability of the FWM process to perform wavelength conversion and mid-span spectral inversion under system conditions that come close to real applications.

The investigations showed for the first time that the full optical bandwidth of the widely employed erbium-doped fibre amplifiers in modern fibre systems can be covered with wavelength converters based on FWM. The experiments confirmed practically error-free wavelength conversion ranges of at least 30 nm down- and at least 15 nm up-conversion for signals at bit rates of 10 Gbit/s.

Mid-span spectral inversion for dispersion compensation was realised in a laboratory set-up in order to explore the feasibility of the FWM process to upgrade to higher bit rates the existing networks made of standard single-mode fibres. By using two orthogonal optical pumps at different wavelengths, penalty-free transmission over 120 km at 2.5 Gbit/s was achieved. By using a similar two-pump scheme, wavelength conversion to both up- and down-wavelengths was realised with efficiencies that remain within a few dBs over several THz frequency range.



Fibreoptic Telecommunications Education in Developing Countries

G. Guekos

The engagement of the Micro- and Optoelectronics Group of the Institute for Quantum Electronics in the cooperation with developing countries started in 1986 with courses by our co-workers at the International Centre for Theoretical Physics (ICTP) in Trieste. Since then, more than 600 physicists and engineers were trained in Trieste and in developing countries following stringent selection criteria regarding basic qualifications in the field of modern communication technologies. With the financial support from the Swiss Development and Cooperation (DEZA) agency of the Ministry of Foreign Affairs, Berne, we have set-up practical laboratory experiments at the ICTP and in developing countries aiming at (i) experimental accompaniment of courses through practical training with measurements in pre-set systems, and, (ii) implementation of concise short to middle term R&D projects in fibreoptic communications and photonics of relevance to developing countries.

We have succeeded in bringing a significant number of physicists and engineers from developing countries in Africa, Asia, and Latin-America in practical contact with a technology that is of key importance to the development of the telecommunication infrastructure of their country. Study curricula, courses and practical laboratory set-ups were implemented in Universities with ETHZ support. Furthermore, we have supported the realisation of local co-operation networks between universities from neighbouring countries.

Formation of Quantum Dots by Misfit Dislocation Superlattices

K. Alchalabi, M. Krejci, H. Zogg

Quantum dot structures are of interest for fundamental research as well as for optoelectronic applications like quantum dot emitters. By using self-assembled dots, e.g. island growth of InAs on a GaAs substrate, no nanometer scale lithography is needed. However, all these self-assembled dots exhibit a distribution in size and corresponding characteristics (e.g. photoluminescence line width), which does not allow to exploit their full advantages.

Another approach to form quantum dots is by epitaxial growth of a lattice mismatched thin layer. Misfit dislocations form to relax the induced mechanical strain as soon as the layer thickness increases a certain limit. It was found that the strain field induced by such dislocations induces a modulation of the bandgap. This modulation may be sufficient that electrons can be captured between the dislocation. Is In addition, with epitaxial lead-chalcogenide structures like PbS/PbSe(100), a completely regular network of misfit dislocations can form. If a thin layer is embedded in a host with different lattice constant, the third dimension is restricted, too, and quantum dots can form. Therefore, completely uniform dots with identical properties should be obtainable over large areas.

We have grown PbSe/PbTe structures by Molecular Beam Epitaxy on BaF_2(100) substrates. The lattice mismatch between PbSe and PbTe is 5%, and the corresponding spacing of the edge type misfit dislocations is 8 nm if full relaxation is achieved. So far, the best structures we obtained show the expected misfit dislocation network. However, complete regularity was obtained over small areas only. Improvements of the growth conditions hopefully will lead to the expected regularity over the whole sample size.

Calculation of band-gap modulation of a 1 nm PbSe layer embedded in PbS (O.A. Mironov et al., Inst. Phys. Conf. Series 144, p. 189, 1995).

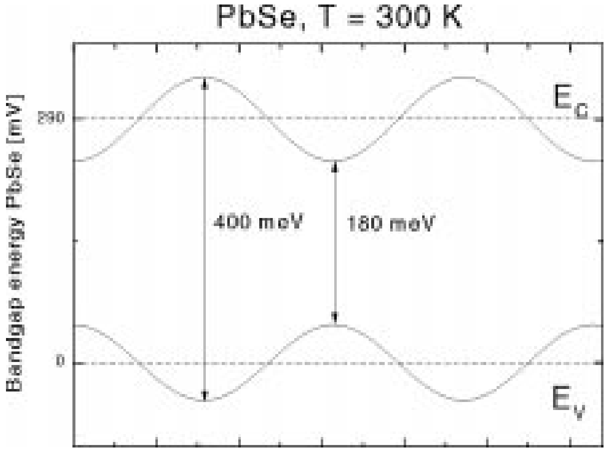
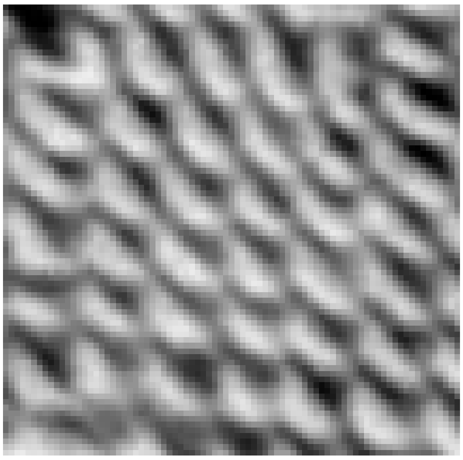


Image of the misfit dislocation network as seen by Transmission Electron Microscopy in a PbTe/PbSe epitaxial structure.



Monolithic Two-Dimensional PbTe Infrared Sensor Array on a Read-Out Si-Chip

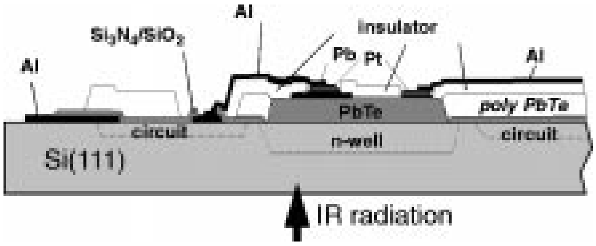
J. John, Y. Athanassov, Q. Lai, H. Zogg, E. Gini

The highest sensitivities of infrared sensors for thermal imaging are obtained with narrow gap semiconductors. Infrared focal plane arrays employing such semiconductors like HgCdTe or InSb are presently fabricated in a hybrid manner with the HgCdTe or InSb chip mated to a Si read-out multiplexer.

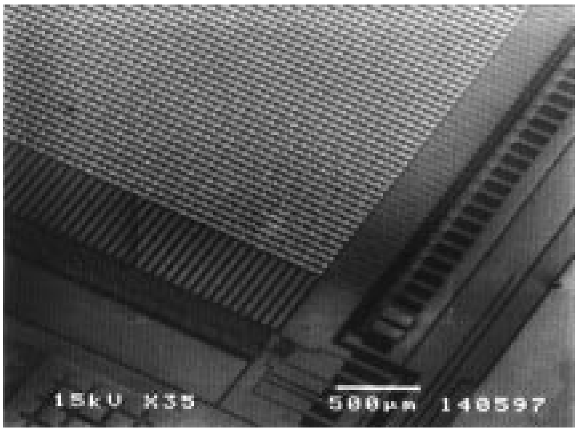
Due to the easy molecular beam epitaxy of narrow gap PbTe and $Pb_{1-x}Sn_xSe$ layers on Si(111)-substrates, a monolithic design becomes possible by growing the infrared sensor material as a thin layer directly onto the Si read-out chip. For practical reasons, postprocessing is used, i.e. the Si-chip is completely fabricated and tested before the sensor layer is deposited.

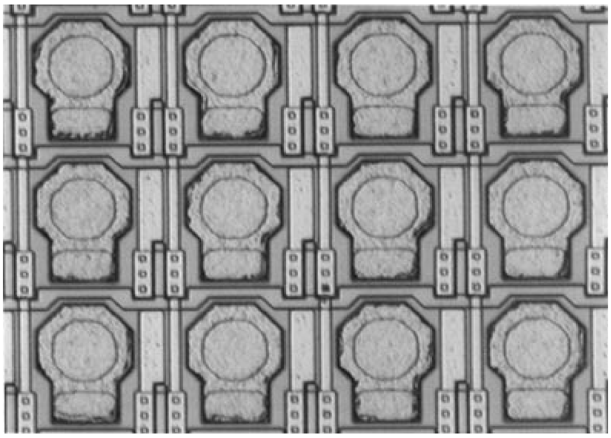
The read-out chips with 128 x 96 pixels on a 75 µm pitch were fabricated in CMOS technology on backside polished Si(111). They contain a switching transistor for each pixel, and a shift register to access the lines serially. The columns are fed out in parallel to a separate amplifier chip. The design and fabrication was done by W. Buttler, Essen, and Fraunhofer-Institut Duisburg, respectively.

The development work is ongoing. The epitaxial growth of the CaF_2 buffer and PbTe sensor layer is performed with a temperature budget of 450˚C for 30 min (for wafer cleaning and growth of the CaF_2 buffer layer), followed by about 3 h at 400˚C for the growth of PbTe.Delineation of the individual pixels and of the blocking Pb-contacts is performed by wet-etching. A new polyimide insulator is presently employed. Via-openings to the substrate for connection of each individual sensor is performed by dry-etching, and for the ohmic contacts, a lift-off technique is used.



Schematic cross section, part of the 2-d array, and some individual pixels at an intermediate processing step (delineated PbTe-pixels with Pb barrier and ohmic contact).



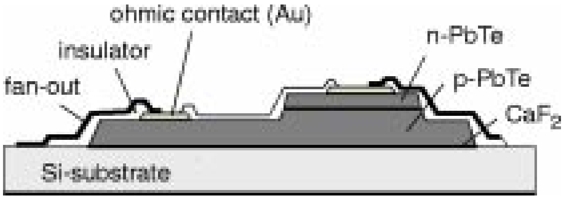


Infrared p-n junction sensors in epitaxial PbTe on Si(111) strucures

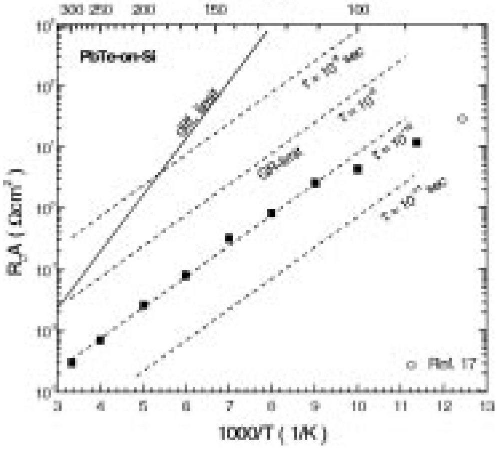
H. Zogg, J. John, Y. Athanassov

The sensitivity of infrared sensors for thermal imaging applications is determined by their noise currents. The ultimate theoretical limit of narrow bandgap p-n junction infrared sensors is the diffusion limit, determined by band-to-band recombination (and can be attained in practice, contrary to larger bandgap devices where g-r recombination dominates). For Schottky barrier infrared sensors (as described on the preceding page), the ultimate limit is given by the standard Schottky theory. We already observe this limit over a large temperature range (300K to 150K) in our best sensor arrays (grown by molecular beam epitaxy on lattice mismatched Si(111) substrates). However, the theoretical diffusion limit for p-n junctions is still near 10 times better. We therefore fabricated p-n junctions in such PbTe layers. Fig. 1 shows a schematic cross section of an individual pixel. The noise currents we observed so far are not at the diffusion limit (solid line in fig. 2), but follow the g-r limit, however. The carrier lifetime is calculated from the experimental results and amounts to ~10 nsec. This corresponds to a diffusion length of ~0.7 m.

The threading dislocation density in the layer used for the fabrication was around 10^8 cm^{-2}. This corresponds to a mean spacing between threading dislocations terminating at the surface of ~0.8 m,just the same value as the diffusion length. We therefore can conclude that the threading dislocations are entirely responsible for the observed additional noise currents, and can extrapolate that a decrease to 10^6 cm^{-2} density is needed to obtain the theoretical diffusion limit down to ~180K. For the Schottky barrier devices of the same type, an about 10 times higher dislocation density is tolerable to still obtain the theoretical limit. Therefore, the lower noise current in p-n junctions has to be payed with a lower dislocation density. We already have obtained dislocation densities of 10^6 cm^{-2} in lead-chalcogenide on Si(111) layers, but have not yet fabricated devices in these layers, however.



Cross section of a p-n IR photodiode fabricated in an epitaxial PbTe-on-Si Layer.

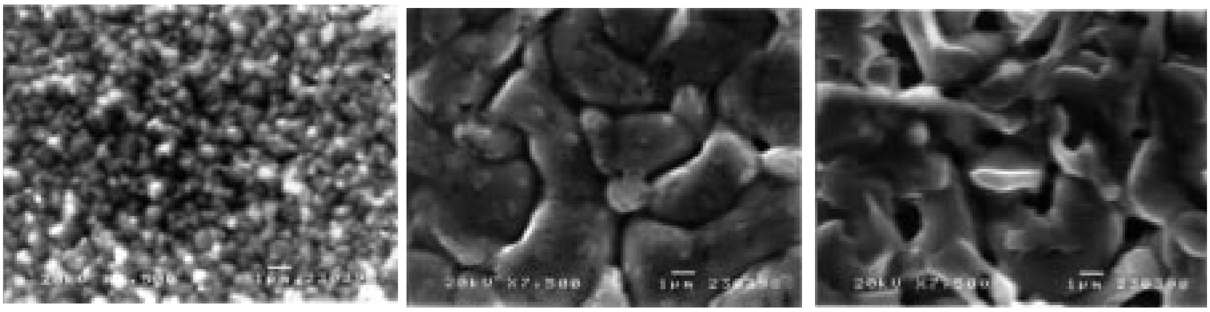


Differential resistance area products RoA (~inverse noise currents) for a p-n PbTe-on-Si IR photodiode. Theoretical diffusion limit (diff.) and experimental results with corresponding g-r lifetimes.

CdTe/CdS thin film solar cells

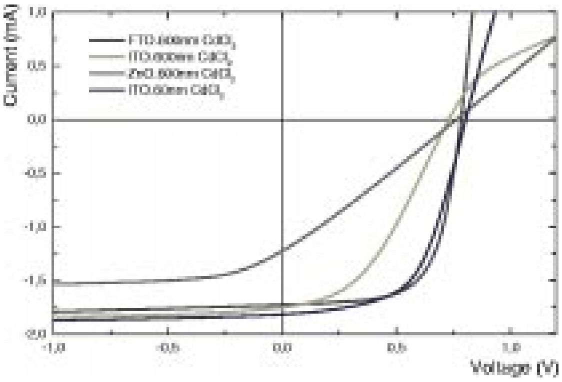
A. Romeo, D. Bätzner, H. Zogg, A.N. Tiwari

CdTe/CdS solar cells are grown on transparent conducting oxide (TCO) coated glass substrates by a process in which all the layers (CdTe, CdS, $CdCl_2$, and ohmic back contact) are grown by vacuum evaporation. Different types of TCO's (ITO, FTO and ZnO) were evaluated for their application as a transparent electrode. Microstructure of CdTe and solar cell efficiency depend on the "$CdCl_2$ treatment" used for the recrystallization of CdTe. As-deposited CdTe layers have small grains in the range of 0.5 to 1 m.However, after the $CdCl_2$ treatment a large increase in the grain size of CdTe is observed and a loss of the (111) preferred orientation (reduced texturing) is measured with x-ray diffraction.



Morphology of as-deposited and recrystallized CdTe layers on ITO (left and middle) and recrystallized CdTe on FTO (right) substrates.

As shown in figure 2 the solar cell properties are sensitive to the amount of $CdCl_2$. The solar cells on ZnO(:Al) layers have low efficiencies of about 2.5% due to the incompatibility of CdS and ZnO at temperatures above 400 ˚C. On FTO, solar cells made with 60 nm $CdCl_2$ have low V_{oc} (~730 mV) and low fill factor (~0.5), while cells treated with 600 nm $CdCl_2$ have V_{oc} in the range of 800-836 mV and the fill factor in the range of 0.64 to 0.70. On ITO substrates this behavior is in contrast; cells with 60 nm $CdCl_2$ have high V_{oc} of 810-838 mV and fill factor of ~0.60.

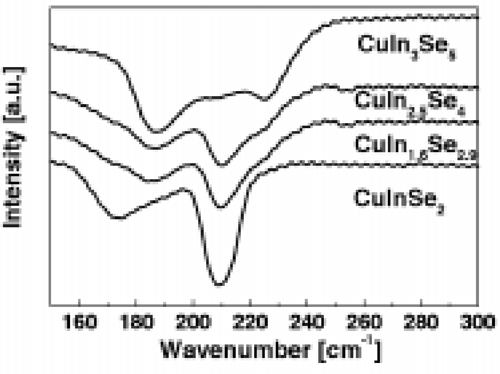


I-V curve of CdTe/CdS solar cells on different TCOs treated with different amounts of $CdCl_2$. Solar cell efficiency on ITO is 10.4% and 11.5% on FTO layers.

Growth and characterization of heteroepitaxial CuIn$_y$Se$_y$ layers and interfaces

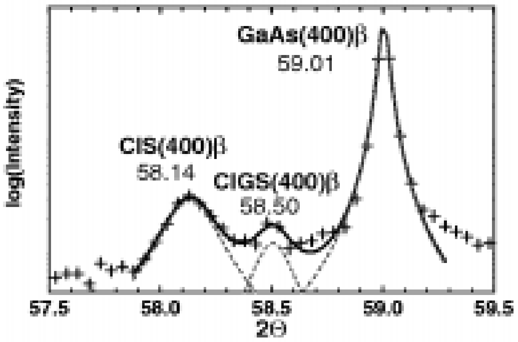
M. Krejci, F. -J. Haug, H. Zogg, A.N. Tiwari

Chalcopyrite ($CuInSe_2$) and defect-chalcopyrite (different In-rich $CuIn_xSe_y$ compositions) compounds are important materials for stable and high efficiency polycrystalline thin film solar cells. Heteroepitaxial layers of $CuIn_xSe_y$ were grown on Si and GaAs substrates by molecular beam epitaxy. Despite of large lattice mismatch and different thermal expansion coefficients, epitaxial layers of “good structural quality” have been obtained. X-ray diffraction (XRD) measurements and the analyses of the lattice vibrational properties by Raman scattering and infrared absorption show (fig. 1) that the $CuIn_{2.5}Se_4$ (β-phase), $CuIn_3Se_5$, and $CuInSe_2$ are single phase compounds while $CuIn_{1.6}Se_{2.9}$ is a mixture of $CuInSe_2$ (β-phase)and $CuIn_{2.5}Se_4$ (α-phase) compounds.



IR absorption spectra and XRD of epitaxial CuInxSey/Si(111) layers.

Transmission electron microscopy (TEM), Rutherford backscattering spectroscopy and XRD were used to investigate the substrate-layer interfaces. In the case of $CuIn_xSe_y$/Si an interfacial $CuSi_xSe_y$ layer is formed during the growth of the epitaxial layer. However, for $CuIn_xSe_y$/GaAs, a strong diffusion of Ga into the $CuIn_xSe_y$ is observed. XRD measurements show the formation of the $Cu(In,Ga)Se_2$ quaternary compound at the interface.



XRD of $CuIn_xSe_y$/GaAs shows the formation of an interfacial $Cu(In,Ga)Se_2$ compound.

Wide gap chalcopyrites for advanced thin film solar cells

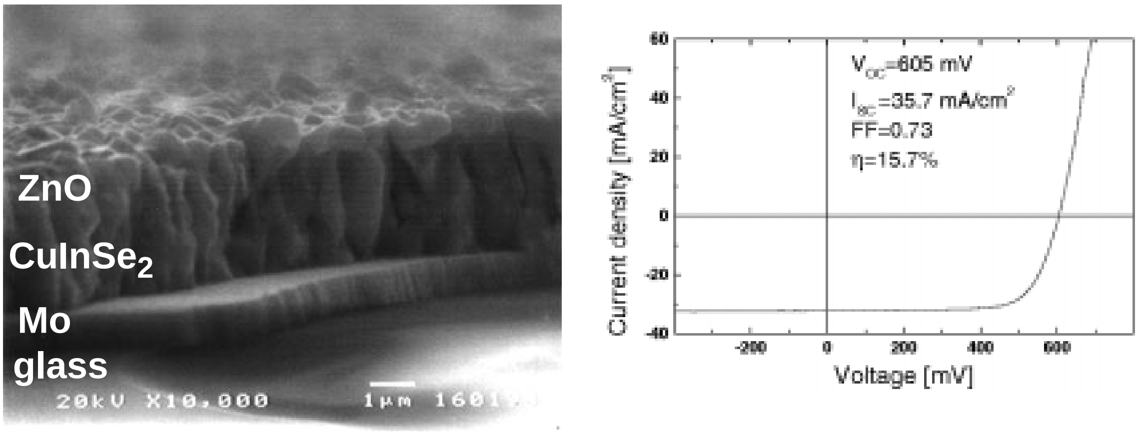
F.-J. Haug, M. Krejci, H. Zogg, A.N. Tiwari

Ternary compounds like $CuInSe_2$ (CIS) or $CuGaSe_2$ (CGS) are usually referred to as chalcopyrites because of their crystal structure. CIS is a suitable material for thin film solar cells and by addition of Ga the bandgap can be adjusted to match the solar spectrum.

Heteroepitaxial layers of $CuGa_xSe_y$ on Si and GaAs substrates have been grown and their structural and optoelectronic properties have been characterized with a variety of methods. One of the objectives is the development of tandem or composition graded polycrystalline thin film solar cells based on $CuGa_xSe_y$ (E_g=1.68 eV) and $Cu(In,Ga)Se_2$ (E_g=1.0-1.2 eV). This required the development of a chemical bath deposition process for the growth of n-type CdS window layers and the sputter-deposition of ZnO as a transparent conducting electrode.

A rf magnetron sputtering system has been installed and the growth conditions have been optimized to grow highly transparent (about 85% transparency in the VIS-NIR spectrum) and conducting (about 10 $\Omega/_{sq}$) ZnO:Al and ZnO layers.

The absorber layer is deposited by coevaporation from four elemtal sources in a vacuum system. Solar cells in the superstrate and substrate configuration have been grown on ZnO:Al/glass and Mo/glass substrates, respectively. The work on $CuGa_xSe_y$/ZnO superstrate solar cells is in the initial stage. However, we have developed a process for the growth of $Cu(In,Ga)Se_2$ layers on Mo/glass with “optimum” composition profile and a “good” microstructure, and fabricated ZnO/CdS/$Cu(In,Ga)Se_2$/Mo/glass solar cells. The efficiencies are in the range of 12 to 16%. Figure shows a SEM cross-section image and I-V characteristics of a $Cu(In,Ga)Se_2$ solar cell in substrate configuration.



SEM cross-section and I-V characteristics of a 15.7% efficiency thin film solar cell.

PUBLICATIONS 1998

Microelectronics and Optoelectronics Laboratory

Books, Book Chapters and Reviews

R. Bauknecht
"InP Double Heterojunction Bipolar Transistors for Driver Circuits in Fiber Optical Communication Systems"
Hartung-Gorre Verlag Konstanz, Series in Microelectronics, **72**, 203 pages,
ISBN 3-89649-264-0, 1998

J. Eckner
"Semiconductor Optical Amplifiers: Optimization of Polarization and Monolithical Integration in Ridge Waveguide Bulk InGaAsP/InP"
Hartung-Gorre Verlag Konstanz, Series in Quantum Electronics, **8**, 201 pages,
ISBN 3-89649-375-2, 1998

G. Guekos (Ed.)
"Photonic Devices for Telecommunications"
Springer Verlag, Hardcover, 404 pages, ISBN 3-540-64318-4, 1998

R. Hess
"Ultrafast All-Optical Time Demultiplexer for Optical Telecommunication Systems"
Hartung-Gorre Verlag Konstanz, Series in Quantum Electronics, **6**, 120 pages,
ISBN 3-89649-297-7, 1998

R. Krähenbühl
"Electro-Optic Space Switches in InGaAsP/InP for Optical Communication"
Hartung-Gorre Verlag Konstanz, Series in Quantum Electronics, **4**, 202 pages,
ISBN 3-89649-267-5, 1998

Q. Lai
"Silica on Silicon Waveguides with Square diffused Structure and their Components for Optical Fiber Communication"
Hartung-Gorre Verlag Konstanz, Series in Quantum Electronics, **7**, 135 pages,
ISBN 3-89649-314-0, 1998

P. Nizzola
"Clock and Data Recovery Circuit for Protocol- and Bitrate-Independent Data Networks"
Hartung-Gorre Verlag Konstanz, Series in Microelectronics, *76*, 117 pages,
ISBN 3-89649-353-1, 1998

Journal Publications

Y. Acremann, T. Heinzel, K. Ensslin, M. Holland, E. Gini and H. Melchior
"Individual Scatterers as Microscopic Origin of Equilibration between Spin-Polarized Edge Channels in the Quantum Hall Regime"
Physical Review B, **59**, pp. 2116 - 2119, Jan. 1999

D. Chiaroni, B. Lavigne, L. Hamon, A. Jourdan, F. Dorgeuille, C. Janz, E. Grard, M. Renaud, R. Bauknecht, C. Graf, H.P. Schneibel and H. Melchior
"Experimental Validation of an All-Optical Network Based on 160 Gbit/s Throughput Packet Switching Nodes"
Proc. ECOC’98, pp. 573 - 574, Sept. 1998

G. Contestabile, F. Martelli, A. Mecozzi, L. Graziani, A. D'Ottavi, P. Spano,
G. Guekos, R. Dall'Ara and J. Eckner
"Efficiency Flattening and Equalization of Frequency Up- and Down-Conversion Using Four-Wave Mixing in Semiconductor Optical Amplifiers"
IEEE Photonics Techn. Letters, **10**, pp. 1398 - 1400, Oct. 1998

G. Contestabile, M. Greco, F. Martelli, A. Mecozzi, A. D'Ottavi, P. Spano,
R. Dall'Ara and G. Guekos
"Frequency Up- and Down-Conversion with Constant Efficiency and Signal-to-Noise Ratio using Four-Wave Mixing in Semiconductor Optical Amplifiers"
Conf. Digest, 1998 IEEE International Semiconductor Laser Conference, Nara, Japan, pp. 31 - 32, Oct. 1998

A. Corchia, C. Antonini, A. D'Ottavi, A. Mecozzi, F. Martelli, P. Spano, G. Guekos and R. Dall'Ara
"Dispersion Compensation using Mid-Span Spectral Inversion without Frequency Shift "
Proc. ECOC’98, Madrid, pp. 511 - 512, Sept. 1998

B. Dhoedt, R. Baets, P. van Daele, P. Heremans, J. van Campenhout, J. Hall,
R. Michalzik, H. Thienpont, R. Vounckx, A. Neyer, D.C. O’Brien, J. van Koetsem and A. Schmid
"Optically Interconnected Integrated Circuits to solve the CMOS Interconnect Bottleneck"
Electronic Components & Technology Conference, Seattle, Washington, USA,
pp. 992 - 998, May 1998

F. Dorgeuille, B. Lavigne, J.Y. Emery, M. Di Maggio, J. Le Bris, D. Chiaroni,
M. Renaud, R. Bauknecht, H.P. Schneibel, C. Graf and H. Melchior
"Fast Optical Amplifier Gate Array for WDM Routing and Switching Applications"
OFC’98 Technical Digest, Vol. 2, pp. 42 - 44, Feb. 1998

A. D'Ottavi, P. Spano, G. Hunziker, R. Paiella, R. Dall'Ara, G. Guekos and K. J. Vahala
"Wavelength Conversion at 10 Gb/s by Four-Wave Mixing over a 30-nm Interval"
IEEE Photon. Technol. Lett., **10**, pp. 952 - 954, July 1998

R. Fluck, R. Häring, R. Paschotta, E. Gini, U. Keller and H. Melchior
"Eyesafe Pulsed Microchip Laser using Semiconductor Saturable Absorber Mirrors"
Applied Physics Letters, **72**, pp. 3272 - 3275, June 1998

P. Gambini, M. Renaud, Ch. Guillemot, F. Callegati, I. Andonovic, B. Bostica, D. Chiaroni, G. Corazza, S.L. Danielson, P. Gravey, P. Bukhave Hansen, M. Henry, Ch. Janz, A. Kloch, C. Raffaelli, M. Schilling, A. Talneau, L. Zucchelli and R. Krähenbühl,
"Transparent Optical Packet Switching: Network Architecture and Demonstrators in the KEOPS Project"
IEEE Journal on Selected Areas in Communications, **16**, pp. 1245 - 1259, Sept. 1998

E. Gini, W. Hunziker and H. Melchior
"Polarization Independent InP WDM Multiplexer/Demultiplexer Module"
Journal of Lightwave Technology, **16**, pp. 625 - 630, April 1998

F. Girardin, G. Guekos and A. Houbavlis
"Gain Recovery of Bulk Semiconductor Optical Amplifiers"
IEEE Photon. Technol. Lett., **10**, pp. 784 - 786, June 1998

F. Girardin, G. Guekos and A. Mecozzi
"Nearly Degenerate Four-Wave Mixing in Semiconductor Optical Amplifiers"
Proc. CLEO/Europe ‘98, Glasgow, UK, paper CTh H18, Sept. 1998

F. Girardin, J. Leuthold, P. A. Besse, E. Gamper, W. Vogt, G. Guekos and H. Melchior
"Monolithically Integrated MZI-SOA Configuration for Polarization Independent Optical Phase Conjugation with Pump Filtering"
Conf. Digest, 1998 IEEE International Semiconductor Laser Conference, Nara, Japan, pp. 37 - 38, Oct. 1998

K. Hamamoto, E. Gini, C. Holtmann, and H. Melchior
"Single Transverse Mode Active Multimode Interferometer InGaAsP/InP Laser Diode"
IEE Electronics Letters, **34**, pp. 462 - 464, March 1998

K. Hamamoto, E. Gini, C. Holtmann and H. Melchior
"Single Transverse Mode Active MMI InGaAsP/InP Laser Diode"
Proc. 1998 Integrated Photonics Research Conference, Victoria B.C. Canada, pp. 186 - 188, April 1998

R. Hess, M. Caraccia-Gross, W. Vogt, E. Gamper, P.A. Besse, M. Dülk, E. Gini,
B. Mikkelsen, M. Vaa, K.S. Jepsen, K.E. Stubkjaer, S. Bouchoule and H. Melchior
"All-Optical Demultiplexing of 80 to 10 Gb/s Signals with Monolithic Integrated High-Performance Mach-Zehnder Interferometer"
IEEE Photonics Technology Letters, **10**, pp. 165 - 167, Jan. 1998

R. Hess, M. Duelk, W. Vogt, E. Gamper, E. Gini, P.A. Besse, K.S. Jepsen,
B. Mikkelsen, M. Vaa, H.N. Poulsen, A.T. Clausen, K.E. Stubkjaer, S. Bouchoule and H. Melchior
"Simultaneous all-Optical Add and Drop Multiplexing of 40 Gb/s OTDM Signals using Monolithically Integrated Mach-Zehnder Interferometer"
Technical Digest, OFC'98, pp. 310 - 311, Feb. 1998.

R. Hess, M. Duelk, W. Vogt, E. Gamper, E. Gini, P.A. Besse, K.S. Jepsen,
B. Mikkelsen, M. Vaa, H.N. Poulsen, A.T. Clausen, K.E. Stubkjaer, S. Bouchoule,
F. Devaux and H. Melchior
"Simultaneous All-Optical Add and Drop Multiplexing of 40 Gbit/s OTDM Signals using Monolithically Integrated Mach-Zehnder Interferometer"
IEE Electronics Letters, **34**, pp. 579 - 580, March 1998

R. Hess, M.W. Chbat, E. Grard, L. Berthelon, A. Jourdan, P.A. Perrier, A. Leclert,
B. Landousies, A. Ramdane, N. Parnis, E.V. Jones, E. Limal, H.N. Poulsen,
R.J.S. Pedersen, N. Flaarønning, D. Vercauteren, M. Puleo, E. Ciaramella, G. Marone,
W. van Parys, P.M. Demeester, P.J. Gødsvang, T. Olsen, D.R. Hjelme and H. Melchior
"Toward Wide-Scale All-Optical Transparent Networking: The ACTS Optical Pan-European Network (OPEN) Project"
IEEE Journal on Selected Areas in Communications, **16**, pp. 1226 - 1244, Sept. 1998

C. Holtmann
"Integration and Applications of III-V Semiconductor Optical Amplifiers"
Proc. European Conference on Optical Communication, ECOC'98, pp. 499 - 500, Sept.1998

D. Huber, M. Bitter, S. Romier, I. Schnyder, T. Morf, C. Bergamaschi, H. Jäckel and R. Bauknecht
"23 GHz Monolithically Integrated InP/InGaAs PIN/HBT-Receiver with 12 THzΩ Gain-bandwidth Product"
Proc. IPRM'98, Tsukuba, Japan, pp. 447 - 450, May 1998

G. Hunziker, R. Paiella, A. D'Ottavi, P. Spano, R. Dall'Ara, G. Guekos and K. Vahala
"30 nm Wavelength Conversion at 10 Gb/s by Four-Wave Mixing in a Semiconductor Optical Amplifier"
OFC'98 Technical Digest, pp. 108 - 109, Feb.1998

W. Hunziker
"Ways to Cost Effective Packaging: Waveguide Tapers and Passive Self-Alignment"
Proc. IEEE/LEOS, **1**, pp. 36 - 37, Dec.1998

Q. Lai, M. Lanker, W. Hunziker and H. Melchior
"Tunable Wavelength-Selection Switch and Multiplexer/Demultiplexer Based on Asymmetric Silica-on-Silicon Mach-Zehnder Interferometer"
Electronic Letters, **34**, pp. 266 - 267, Feb. 1998

Q. Lai, W. Hunziker and H. Melchior
"Low-Power Compact 2 x 2 Thermooptic Silica-on-Silicon Waveguide Switch with Fast Response"
IEEE Photonics Technology, **10**, pp. 681 - 683, May 1998

J. Leuthold, P.A. Besse, J. Eckner, E. Gamper, M. Dülk and H. Melchior
"All-Optical Space Switches with Gain and Principally Ideal Extinction Ratios"
IEEE Journal of Quantum Electronics, **34**, pp. 622 - 633, April 1998

J. Leuthold, J. Eckner, E. Gamper, P.A. Besse and H. Melchior
"Multimode Interference Couplers for the Conversion and Combining of Zero- and First-Order Modes"
Journal of Lightwave Technology, **16**, pp. 1228 - 1239, July 1998

J. Leuthold, P.A. Besse, E. Gamper, M. Dülk, S. Fischer and H. Melchior
"Cascadable Dual-Order Mode All-Optical Switch with Integrated Data- and Control-Signal Separators"
IEE Electronics Letters, **34**, pp. 1598 - 1600, Aug. 1998

J. Leuthold, P.A. Besse, E. Gamper, M. Dülk, W. Vogt and H. Melchior
"Cascadable MZI-All-Optical Switch with Separate Ports for Data- and Control-Signals"
Proc. ECOC'98, Madrid, Spain, pp. 463 - 464, Sept. 1998

J. Leuthold, F. Girardin, P.A. Besse, E. Gamper, G. Guekos and H. Melchior
"Polarization Independent Optical Phase Conjugation with Pump-Signal Filtering in a Monolithically Integrated Mach-Zehnder Interferometer Semiconductor Optical Amplifier Configuration"
IEEE Photonics Technology Letters, **10**, pp.1569 - 1571, Nov. 1998

A. Mecozzi, G. Contestabile, F. Martelli, L. Graziani, A. D'Ottavi, P. Spano,
G. Guekos, R. Dall'Ara and J. Eckner
"Efficiency Equalization of Up- and Down-Conversion Four-Wave Mixing in a Semiconductor Optical Amplifier using two Pumps with Orthogonal Polarization"
OFC'98 Technical Digest, pp. 107 - 108, Feb.1998

A. Mecozzi, G. Contestabile, F. Martelli, L. Graziani, A. D'Ottavi, P. Spano,
R. Dall'Ara, J. Eckner, F. Girardin and G. Guekos
"Optical Spectral Inversion without Frequency Shift by Four-Wave Mixing Using Two Pumps with Orthogonal Polarization"
IEEE Photonics Techn. Letters, **10**, pp. 355 - 357, March 1998

A. Mecozzi, G. Contestabile, L. Graziani, F. Martelli, A. D’Ottavi, P. Spano,
R. Dall’Ara and J. Eckner
"Polarization-Insensitive Four-Wave Mixing in a Semiconductor Optical Amplifier"
Applied Physics Letters, **72**, pp. 2651 - 2653, May 1998

C. Nadler, M. Lanker, E. Wildermuth, W. Hunziker and H. Melchior
"Polarization Insensitive Wavelength Multiplexers Using Stress Release Grooves"
Proc. European Conference on Optical Communication, ECOC’98, pp. 129 - 130, Sept. 1998

S. Pajarola, G. Guekos and H. Kawaguchi
"Dual-Polarization Optical Pulse Generation using a Mode-Locked two-arm External Cavity Diode Laser"
Optics Communications, **154**, pp. 39 - 42, Aug. 1998

S. Pajarola, G. Guekos, and H. Kawaguchi
"Data Transission on Optically Generated Millimeter-Waves using a Dual-Polarization Emission External Cavity Diode Laser"
Proc. 1998 International Zurich Seminar on Broadband Communications, Switzerland, pp. 59 - 62, Feb.1998 (IEEE Catalog No. 98TH8277)

S. Pajarola, G. Guekos and H. Kawaguchi
"Antenna Remote Fiber Feeding Using a Dual-polarization External Cavity Diode Laser"
Proc. ICT'98 Intern. Conf. on Telecommunications, Porto Carras, Greece,
pp. 344 - 347, June 1998

S. Pajarola, G. Guekos and H. Kawaguchi
"Optical Millimeter-Wave Transmission Using a Dual-polarization External Cavity Diode Laser"
IEEE Photon. Technol. Lett., 10, pp. 1021 - 1023, July 1998

T. Pliska, D. Fluck, P. Günter, E. Gini, L. Beckers, A. Eckau, C. Buchal and
H. Melchior
"Efficient Birefringence Phase-Matched Blue Light Second-Harmonic Generation in a $KNbO_3$ Ridge Waveguide"
Proc. Nonlinear Guided Waves & Their Applications ‘98, Optical Soc., America, April 1998

T. Pliska, D. Fluck, G. Günter, E. Gini, L. Beckers, C. Buchal and H. Melchior
"Birefringence Phase-Matched Blue Light Second Harmonic Generation in a $KNbO_3$ Ridge Waveguide"
Applied Physics Letters, **72**, pp. 2364 - 2366, May 1998

H.N. Poulsen, K.S. Jepsen, A.T. Claussen, A. Buxens, K.E. Stubkjaer, R. Hess, M. Dülk and H. Melchior
"Fast Optical Signal Processing in High Bit Rate OTDM Systems"
Proc. IEEE/LEOS, **1**, pp. 67 - 68, Dec. 1998

I. Tomkos, I. Zacharopoulos, E. Roditi, D. Syvridis, F. Girardin, L. Occhi and A. Uskov
"Highly Performing Wavelength Converter Based on Dual Pump Wave Mixing in Semiconductor Optical Amplifier"
Proc. LEOS '98, Orlando, USA, pp. 71 - 72, Dec. 1998

E. Wildermuth, Ch. Nadler, M. Lanker, W. Hunziker and H. Melchior
"Penalty-free Polarisation Compensation of SiO2/Si Arrayed Waveguide Grating Wavelength Multiplexers using Stress Release Grooves"
IEE Electronics Letters, **34**, pp. 1661 - 1663, Aug. 1998

L. Zucchelli, D. Di Bella, G. Fornuto, P. Gambini, D. Re, F. Delorme, R. Kraehenbuehl and H. Melchior
"An Experimental Optical Packet Synchroniser with 100 ns Range and 200 ps Resolution"
Proc. ECOC'98, pp. 587 - 588, Sept. 1998

ORAL PRESENTATIONS 1998

L. Alimkulova
"The Electrical, Structural and Optical Properties of AlGaInAs/InGaAs Quantum Well Structures"
Poster 40th Electronic Materials Conference, University of Virginia, Charlottesville, Virginia, USA, June 1998

L. Alimkulova
"The Low Loss Waveguides based on InAlAs/InP Materials"
Meeting Priority Program Optique, Geneva, June 18, 1998

L. Alimkulova
"Linear and Nonlinear Optical Properties of Low-Dimensional Semiconductor Nanostructures"
Meeting Priority Program Optique, Berne, Switzerland, Nov. 5, 1998

M. Caraccia-Gross
"Optically Controlled Mach-Zehnder Interferometers: Modeling and Experiment"
Symposium on Ultrafast Photonic Processing and Networks, The Rank Prize Funds, Grasmere, Great-Britain, April 20 - 23, 1998

D. Chiaroni, B. Lavigne, L. Hamon, A. Jourdan, F. Dorgeuille, C. Janz, E. Grard, M. Renaud, R. Bauknecht, C. Graf, H.P. Schneibel and H. Melchior
"Experimental Validation of an All-Optical Network Based on 160 Gbit/s Throughput Packet Switching Nodes"
ECOC'98, Madrid, Spain, Sept. 20 - 24, 1998

F. Girardin, G. Guekos and A. Mecozzi
"Nearly Degenerate Four-Wave Mixing in Semiconductor Optical Amplifiers"
Conference on Lasers and Electro-Optics Europe, CLEO/Europe '98, Glasgow, UK, Sept. 14 - 18, 1998

F. Girardin, J. Leuthold, P. A. Besse, E. Gamper, W. Vogt, G. Guekos and H. Melchior
"Monolithically Integrated MZI-SOA Configuration for Polarization Independent Optical Phase Conjugation with Pump Filtering"
1998 IEEE International Semiconductor Laser Conference, Nara, Japan, Oct. 4 - 8, 1998

K. Hamamoto, E. Gini, C. Holtmann and H. Melchior
"Single Transverse Mode Active MMI InGaAsP/InP Laser Diode"
1998 Integrated Photonics Research Conference, Victoria B.C. Canada, March 30 - April 1, 1998

C. Holtmann
"Integration and Applications of III-V Semiconductor Optical Amplifiers"
Invited presentation at European Conference on Optical Communication ECOC'98, Sept. 20 - 24, 1998

D. Huber, S. Romier, I. Schnyder, R. Bauknecht, M. Bitter, T. Morf, C. Bergamaschi and H. Jäckel
"23 GHz Monolithically Integrated InP/InGaAs PIN/HBT-Receiver with 12 THzΩ Gain-Bandwidth Product"
International Conference on Indium Phosphide and Related Materials IPRM, Tsukuba, Japan, May 11 - 15, 1998

W. Hunziker
"Packaging of Optoelectronic Components: Fiber Array Connections and Mounting Platforms"
Seminar at Institute of Microsystems of the Swiss Federal Institute of Technology, Lausanne, Switzerland, Jan.19, 1998

W. Hunziker
"Ways to Cost Effective Packaging: Waveguide Tapers and Passive Self-Alignment"
IEEE/LEOS 11th Annual Meeting, Orlando, Florida, USA, Dec.1 - 2, 1998

M. Lanker, E. Wildermuth, Ch. Nadler,W. Hunziker and H. Melchior
"Technology for Polarization Insensitive Arrayed Waveguide Multiplexers Based on SiO2 on Si"
Workshop on Fibre Optic Passive Components, WFOPC'98, Pavia,
Sept. 18, 1998

K.S. Jepsen, B. Mikkelsen, M. Vaa, H.N. Poulsen, A.T. Clausen, K.E. Stubkjaer, S. Bouchoule, R. Hess, M. Duelk, W. Vogt, E. Gamper, E. Gini, P.A. Besse and H. Melchior
"Simultaneous all-Optical Add and Drop Multiplexing of 40 Gb/s OTDM Signals using Monolithically Integrated Mach-Zehnder Interferometer"
OFC'98, Feb. 1998.

J. Leuthold, P.A. Besse, E. Gamper, M. Dülk, W. Vogt and H. Melchior
"Cascadable MZI-All-Optical Switch with Separate Ports for Data- and Control-Signals"
European Conference on Optical Communication, Madrid, Spain, Sept. 20 - 24 1998

H. Melchior
"Indium Phosphide Waveguide Devices and their Fiber Pigtailing"
Invited Plenary Presentation, 1998 Integrated Photonics Research Conference,
Victoria B.C. Canada, March 30 - April 1, 1998

H. Melchior
"Indium Phosphide Optical Waveguide Switches and Optical Amplifiers"
Seminar, NEC Corporation Research Laboratories, Tsukuba, Japan, May 18, 1998

H. Melchior
"Optoelectronic Waveguide Component Modules"
Seminar, Hitachi Central Research Laboratories, Tokyo, May 10, 1998

H. Melchior
"Optical Waveguide Switches, Amplifiers and Demultiplexers for Fiber-Optical Networks"
Seminar, NTT-Research Laboratories, Atsugi, Japan, May 21, 1998

C. Nadler, M. Lanker, E. Wildermuth, W. Hunziker and H. Melchior
"Polarization Insensitive Wavelength Multiplexers Using Stress Release Grooves"
European Conference on Optical Communication, ECOC'98, Madrid,
Sept. 20 - 24, 1998

S. Pajarola, G. Guekos and H. Kawaguchi
"Antenna Remote Fiber Feeding Using a Dual-polarization External Cavity Diode Laser"
ICT '98, Intern. Conf. on Telecommunications, Porto Carras, Greece, 21 - 25 June, 1998

S. Pajarola, G. Guekos and H. Kawaguchi
"Data transmission on optically generated millimeter-waves using a dual-polarization emission external cavity diode laser"
1998 Intern. Zurich Seminar on Broadband Communications, Zurich, Switzerland, Feb. 17 - 19, 1998

S. Pajarola, L. Occhi, G. Guekos and H. Kawaguchi
"Optical millimeter-wave generation for remote antenna feeding using a dual-polarization external cavity diode laser"
6th MCM COST 259, Duisburg, Germany, Sept. 23 - 25, 1998

T. Pliska, D. Fluck, G. Günter, E. Gini, L. Beckers, C. Buchal and H. Melchior
"Efficient Birefringence Phase-Matched Blue Light Second Harmonic Generation in a $KNbO_3$ Ridge Waveguide"
Nonlinear Waveguide and their Applications Conference, Victoria, B.C. Canada, April 1 - 3, 1998

H.N. Poulsen, K.S. Jepsen, A.T. Claussen, A. Buxens, K.E. Stubkjaer, R. Hess, M. Dülk and H. Melchior
"Fast Optical Signal Processing in High Bit Rate OTDM Systems"
IEEE/LEOS 11th Annual Meeting, Orlando, Florida, USA, Dec. 1 - 4, 1998

L. Zucchelli, D. Di Bella, G. Fornuto, P. Gambini, D. Re, F. Delorme, R. Kraehenbuehl and H. Melchior
"An Experimental Optical Packet Synchroniser with 100 ns Range and 200 ps Resolution"
ECOC’98, Madrid, Spain, Sept. 20 - 24, 1998

Thin Film Physics Group

Journal Publications

M.J. Furlong, M. Froment, M.C. Berhard, R. Cortès, A.N. Tiwari, M. Krejci, D. Lincot and H. Zogg
"Aqueous Solution Epitaxy of CdS Layers on $CuInSe_2$"
Journal Crystal Growth, **193**, pp. 114 - 122, 1998

M. Krejci, A.N. Tiwari, M. Döbeli, V. Zelezny, J. Oswald, V. Vorlicek and H. Zogg
"Epitaxial $CuIn_xSe_y$ Layers of Improved Crystal Quality and Determination of the Crystal Orientation with Raman Spectroscopy"
Inst. Phys. Conference, **152**, pp. 377 - 380, 1998

Z. Shi, H. Zogg, U. Keller
"Thick Crack-Free CaF_2 Epitaxial Layer on GaAs (100) Substrate by Molecular Beam Epitaxy"
Journal Electronic Mat., **27**, pp. 55 - 58, 1998

A.N. Tiwari, F.-J. Haug and H. Zogg
"Dünnschichtsolarzellen aus Verbindungshalbleitern"
VSE Bulletin, **89**, pp. 45 - 49, 1998

H. Zogg and J. John
"Lead Chalcogenide on Silicon Infrared Sensor Arrays"
Opto-Electronics Review, **6**, pp. 37 - 46, 1998

Conference Presentations

K. Alchalabi, J. John and H. Zogg
"Versetzungsgleiten und Reaktionen in Epitaktischem PbTe und PbSe auf Si(111)"
SPG-Meeting, Berne, Switzerland, Feb. 26 - 27, 1998

K. Alchalabi, M. Krejci and H. Zogg
"Bleisalzversetzungsübergitter auf BaF_2(100)"
MBE-Workshop, Hamburg, Germany, Sept. 21 - 23, 1998

F.-J. Haug, M. Krejci, A.N. Tiwari and H. Zogg
"Growth and Application of $Cu(In,Ga)_xSe_y$ Layers"
SPG Meeting, Berne, Feb. 26 - 27, 1998

F.-J. Haug, M. Krejci, A.N. Tiwari, H. Zogg, M. Döbeli, V. Zelezny and V. Vorlicek
"Growth and Structural Characterisation of $CuGa_xSe_y$ Layers"
Poster, 2nd World Conference on PV Solar Energy Conversion, Vienna, Italy,
July 6 - 10, 1998

J. John, H. Zogg, K. Alchalabi and Y. Athanassov
"Photovoltaic Lead-Salt on Silicon IR-Sensors for the MWIR: Experimental vs Theoretical Performance"
MRS (Material Research Society) Fall Meeting, Boston, USA, Nov. 30 - Dec. 4, 1998

M. Krejci, F.-J. Haug, A.N. Tiwari and H. Zogg
"Interfaces Between Epitaxial $CuIn_xSe_y$ and Si and GaAs Substrates"
SPG Meeting, Berne, Feb. 26 - 27, 1998

M. Krejci, A.N. Tiwari, F.-J. Haug and H. Zogg
"Investigation of the Interfaces Between Substrate and Epitaxial $CuIn_xSe_y$ Layers"
Poster, 2nd World Conference on PV Solar Energy Conversion, Vienna, Italy,
July 6 - 10, 1998

V. Nadenau, H.-W. Schock, M. Krejci, F.-J. Haug, A.N. Tiwari and H. Zogg
"Microstucture of Cu-rich $CuGaSe_2$ thin films"
Poster, Polyse, Stuttgart, Germany, Sept. 13 - 18, 1998

A. Romeo, A.N. Tiwari, H. Zogg, M. Wagner and J.R. Günter
"Influence of Transparent Conducting Ocides on the Properties of CdTe/CdS Solar Cells"
Poster, 2nd World Conference on PV Solar Energy Conversion, Vienna, Italy,
July 6 - 10, 1998

S. Schön, H. Zogg and U. Keller
"Growth of Novel Broadband High Reflection Mirrors by Molecular Beam Epitaxy"
Xth International Conference on Molecular Beam Epitaxy, Cannes, France,
Aug. 31 - Sept. 5, 1998

A.N. Tiwari, M. Krejci, F.-J. Haug, A. Romeo and H. Zogg
"Dünnschichtsolarzellen aus Verbindungshalbleitern"
National Photovoltaic Meeting, Berne, May 5, 1998

A.N. Tiwari, M. Krejci, F.-J. Haug, H. Zogg, M. Döbeli, V. Zelezny, V. Vorlicek and G. Lippold
"Structural Properties and Identification of In-rich $CuIn_xSe_y$ Phases"
Poster, 2nd World Conference on PV Solar Energy Conversion, Vienna, Italy,
July 6 - 10, 1998

A.N. Tiwari, M. Krejci, F.-J. Haug, H. Zogg, M. Döbeli, V. Zelezny and V. Vorlicek
"Heteroepitaxy of $CuIn_xSe_y$: Material for High Efficiency and Stable Solar Cells"
Poster, Xth International Conference on Molecular Beam Epitaxy, Cannes, France, Aug. 31 - Sept. 5, 1998

A.N. Tiwari, M. Krejci, F.-J. Haug, A. Romeo and H. Zogg
"Dnnschichtsolarzellen aus Verbindungshalbleitern"
SPG Energy Symposium, Airolo, Switzerland, Sept. 25, 1998

H. Zogg
"Epitaxial Lead-Chalcogenide on Silicon Layers for Thermal Imaging Applications"
Invited Paper, Fourth International Conference on Material Science and Material Properties for Infrared Optoelectronics, Kiev, Ukraine, Sept. 28 - Oct. 2, 1998

H. Zogg, J. John and K. Alchalabi
"Low (below 10^6 cm^{-2} Dislocation Densities In Epitaxial Lead-Salt on Si(111) Layers by Multiple Anneals"
MRS (Material Research Society) Fall Meeting, Boston, USA, Nov. 30 - Dec. 4, 1998

Ph.D. and Diploma Theses

of the IQE

1998

PH.D. THESES IN PHYSICS

Eckner, Jürg
"Semiconductor Optical Amplifiers: Optimization of Polarization and Monolithical Integration in Ridge Waveguide Bulk InGaAsP/InP"
Dissertation No. 12792, ETH Zurich, Switzerland, 1998 (Prof. Dr. H. Melchior, Prof. Dr. E. Kapon)

Hess, Rolando
"Ultrafast All-Optical Time Demultiplexer for Optical Telecommunication Systems"
Dissertation No. 12525, ETH Zurich, Switzerland, 1998 (Prof. Dr. H. Melchior, Prof. Dr. K.E. Stubkjaer, Prof. Dr. W. Lukosz)

John, Joachim
"Photovoltaische Bleichalkogenidsensoren für das Mittlere Infrarot"
Dissertation No. 12557, ETH Zurich, Switzerland, 1998 (Prof. Dr. U. Keller, Prof. Dr. M. Tacke, Dr. H. Zogg)

Krähenbühl, Roger
"Electro-Optic Space Switches in InGaAsP/InP for Optical Communication"
Dissertation No. 12498, ETH Zurich, Switzerland, 1998 (Prof. Dr. H. Melchior, Prof. Dr. P. Günter)

Leuthold, Jürg
"Advanced Indium-Phosphide Waveguide Mach-Zehnder Interferometer All-Optical Switches and Wavelength Converters"
Dissertation No. 12991, ETH Zurich, Switzerland, 1998

Nadler, Christoph
"Polarization Insensitive Arrayed Waveguide Grating Wavelength Multiplexers for Optical Communication"
Dissertation No. 12957, ETH Zurich, Switzerland, 1998 (Prof. Dr. H. Melchior & Prof. Dr. P. Günter)

PH.D. THESES IN ELECTRICAL ENGINEERING

Lai, Qun
"Silica on Silicon Waveguides with Square diffused Structure and their Components for Optical Fiber Communication"
Dissertation No. 12600, ETH Zurich, Switzerland, 1998(Prof. Dr. H. Melchior, Prof. Dr. H. Jäckel)

Nizzola, Pietro
"Clock and Data Recovery Circuit for Protocol- and Bitrate-Independent Data Networks"
Dissertation No. 12778, ETH Zurich, Switzerland, 1998 (Prof. Dr. H. Melchior, Prof. Dr. Q. Huang)

Pajarola, Stephan
"Dual-Polarization External Cavity Diode Laser for the Optical Generation of Millimeter-Waves"
Dissertation No. 12633, ETH Zurich, Switzerland, 1998 (Prof. Dr. G. Guekos, Prof. Dr. H. Kawaguchi, Prof. Dr. P. Leuthold)

Schmid, André
"Receiver Arrays for Chip and Board Optical Interconnects"
Dissertation No. 12884, ETH Zurich, Switzerland, 1998 (Prof. Dr. H. Melchior, Prof. Dr. H. Jäckel)

DIPLOMA THESES IN PHYSICS

Acremann, Yves Marc
"Equilibriering von Randzuständen im Quantenhall-Bereich"
ETH Zurich, Switzerland, Winter 1997/1998 (Prof. Dr. K. Ensslin,
Prof. Dr. H. Melchior)

Flück, Eliane
"Thermo-optical Space Switch based on Planar Waveguide Technology with Individuel Heater Control"
ETH Zurich, Switzerland, Summer 1998 (Prof. Dr. H. Melchior)

Schmidt, Hannes
"Organic Light Emitting Diodes: Influence of Electrode Treatment on Device Efficiency and Stability"
ETH Zurich, Switzerland, Summer 1998 (Prof. Dr. H. Melchior)

Zellweger, Christoph
"Characterization of Diode Lasers and Semiconductor Optical Amplifiers"
ETH Zurich, Switzerland, Winter 1997/1998 (Prof. Dr. H. Melchior)

DIPLOMA THESES IN ELECTRICAL ENGINEERING

Franchi, Christian and Moretti, Patrick
"Ansteuerelektronik für optische Schaltmatrizen"
ETH Zurich, Switzerland, Winter 1997/1998 (Prof. Dr. H. Melchior)