Ultrastrong Light-Matter Coupling with Metasurfaces

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Ultrastrong Light-Matter Coupling with Metasurfaces

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presented by

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Abstract

Ultrastrong light-matter coupling is an extreme regime of interaction in which counter rotating coupling terms, which do not conserve energy, and light self-interaction (diamagnetic interaction) become dominant. These give rise to anomalous photon correlations and finite photon populations in the coupled ground state. A quantum phase transition is predicted when matter excitations based on linear dispersion are employed, for which the energy renormalization due to the light self-interaction is predicted to be absent.

The aim of this thesis is to explore the properties of the ultrastrong coupling regime experimentally. This goal is pursued by coupling the cyclotron transition in two dimensional electron gases to resonances in planar metallic resonators. Advancing the understanding and performance of these two components is an auxiliary goal.

In the first part, models describing metallic split ring resonators are introduced and their general properties are discussed. Subsequently, the theory of light-matter interaction, which has been developed for dielectric $\lambda/2$ micro-cavities, is extended to sub-wavelength metallic resonators. Their small mode volume enhances the vacuum electric field amplitude and leads to increased coupling rates.

The influence of the resonator geometry on the coupling rate is studied experimentally showing resonator dependent variations in the coupling rate by a factor of more than 3. Good agreement with the extended theory is found.

Quenching of the radiative decay rate of the cyclotron transition in the two dimensional electron gas as consequence of the small number of coupled electrons is observed. This is an advantageous feature, since it allows to observe the intrinsic line width of the cyclotron transition, which usually is radiative broadened due to collective coupling to free space radiation.

Superconducting metamaterials are explored for application to the ultrastrong coupling regime. The tuning of the resonator properties across the superconducting phase transition are studied. A resonator geometry exhibiting a Q-factor switching of 100 % and intensity transmission modulation of more than 99 % is developed. Detection of a single resonator is demonstrated.

Resumaziun

Colligiaziun ultraferma da glisch e materia ei in reschim d'interacziun extrem el qual las contribuziuns d'interacziun cuntercurrentas e l'interacziun dalla glisch cun sesez domineschan. Quei meina tier correlaziuns anomalas dallas particlas dalla glisch (fotons) e tier ina populaziun da fotons finita el livel fundamental. En cass spezials, cu materials cun dispersiun lineara vegnan colligiai, ei vegniu predetg ina transiziun da fasa quantistica.

Igl intent da questa lavur ei d'explorar las atgnadads dil reschim da colligiaziun ultraferma cun experiments. La transiziun denter dus orbits da cyclotron en in gas d'electrons bidimensiunal vegn colligiada cun resonanzas dad in resonatur planar da metal per contonscher quella finamira. Capir ils principis d'operaziun, determinar ils facturs limitonts da quels dus elements e sviluppar versiuns optimadas ein finamiras secundaras da questa lavur.

En l'emprema part vegnan models per descriver resonaturs en metal en fuorma da tscherchels fess presentai e las atgnadads dils resonaturs vegnan descretas. La teoria da l'interacziun da glisch cun matteria vegn silsuenter generalisada per resonaturs metallics cun dimensiuns pli pintgas che l'unda dalla glisch. Experiments conferman ina gronda influenza dalla geometria sin la fermezia dalla colligiaziun. La rata da colligiaziun variescha per pli ch'in factur treis per differentas geometrias. Ils resultats corrispundan bein a las valetas predetgas en simulaziuns.

El reschim da colligiaziun ultraferma vegn la rata da sminuaziun dalla transiziun da cyclotron supprimida. Quella modificaziun dalla rata da sminuaziun ei duida al pign diember dad electrons involvai en l'interaziun denter glisch e materia. Quei ei d'aventatg perquei ch'ei lubescha d'observar la larghezia dalla lingia intrinsica senza slargiaments dui a radiaziun egl ambient.

Resonaturs ord materials superconductivs vegnan explorai per applicaziuns el reschim da colligiaziun ultraferma. La modificaziun dallas atgnadads dils resonaturs en dependenza dallas atgnadads dil material superconductiv ei vegnida mesirada e vegn explicada. In resonatur superconductiv ei vegnius svilupaus pil qual la transiziun da phasa superconcutiva meina tier ina modulaziun dil factur da qualitad da 100% ed ina modulaziun dalla transmissiun da sur 99%. La detecziun dad in singul resonatur vegn demonstrada.