Secondary electron emission at high current densities with special consideration of practical applications

Author(s):
Jenny, Dietrich Alfred

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Secondary Electron Emission at High Current Densities with Special Consideration of Practical Applications

THESIS

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BY

Dietrich Alfred Jenny

from Ennenda (Kt. Glarus)

Accepted on the recommendation of

Prof. Dr. F. Tank and Prof. Dr. G. Busch

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IV. Summary and Conclusions

The qualitative theoretical picture of the processes and conditions determining the multiplication ratio $\delta$ of a composite secondary electron emitter (SEM) based on the excess metal emission center concept proposed by R. Suhrmann and W. Berger [1] is capable of explaining the experimental results obtained during this investigation as well as the majority of the previously published data. The $\delta$ appears to be determined by the excess metal concentration and distribution in the part of the SEM where the primary electrons interact with the solid to release the secondary electrons (interaction region) and a maximum $\delta$ is obtained at a certain optimum excess metal concentration.

The newly discovered bombardment activation is a consequence of the increasing excess metal concentration during operation of the SEM as such, till the maximum $\delta$ is reached at the optimum concentration after which the $\delta$-decay sets in towards higher concentrations. The production of excess metal must be attributed to the decomposition of the SEM compound at the surface by electron and positive ion bombardment, whereby the in general volatile nonmetallic component evaporates leaving the nonvolatile metallic component. It is shown that the diffusion coefficient of the metallic component as excess metal in the SEM substance as well as the surface structure of the SEM are of utmost importance concerning the activation and $\delta$-decay characteristics and the maximum attainable $\delta$.

The presence of the nonmetallic component as active residual gas reduces the excess metal production due to recombination thus slowing down the $\delta$-decay, which is observed by the effect of the exposure of SEMs to each other in a multistage SEE multiplier where the evaporation of the nonmetallic component from the
following stage due to decomposition acts against on the excess metal production at the surface of the proceeding stage by recombination.

In the unexposed case the active residual gas can be introduced deliberately to maintain a certain pressure at which a dynamic equilibrium of the excess metal producing and reducing processes at the surface of the SEM is established leading to a constant excess metal concentration and distribution in the interaction region resulting in a constant \( \delta \). A similar dynamic equilibrium can be attained by replacing the excess metal reducing process by evaporation of the metallic component instead of the active residual gas recombination which requires a critical operating temperature in place of the active residual gas.

The life of a SEM operated in the nonequilibrium condition is determined by the minimum useful \( \delta \) for a particular practical application which is reached after a certain time of operation as a consequence of the \( \delta \)-decay which is essentially independant of the thickness of the SEM coating. On the other hand the life of a SEM operated at dynamic equilibrium is proportional to the coating thickness which is gradually reduced due to the removal of SEM substance by positive ion bombardment and the decomposition processes, so that appreciably longer life can be attained with a sufficiently thick SEM coating as compared with the nonequilibrium case. Due to the fact that the \( \delta \)-decay is the more rapid the higher the operating current density, this possibility of extending the life is of particular interest at high current densities where the useful life in the nonequilibrium operating condition is not sufficient to be of practical usefulness.

The above principles of the theoretical picture lead to the successful development of a SEM which is capable of maintaining a \( \delta \) in the order of 4 and higher at a primary energy of 300 volts with a secondary current density of about 2 amp/cm² for several hundred hours without any sign of a \( \delta \)-decay if operated at dynamic equilibrium which result indicates that it ought to be possible to attain a life of more than a thousand hours. The SEM coating consists of a mixture of magnesium and barium oxide with a respective molar mixture ratio of 4:1 and a thickness of a few thousand
angstroms. The active residual gas is oxygen and the pressure required to establish the dynamic equilibrium is about $5 \times 10^{-8}$ mmHg for the above oxide mixture ratio but it can be varied within a wide range by changing the latter.

Although a number of results of secondary importance supporting the theoretical picture were obtained in the experimental part the data is by far not complete to allow numerical evaluations and a great deal of work is to be done to clear up the controversial points of the theory.

The main obstacle in the investigation of the influence of the numeros variables is the fact that the reproducability as to the $\delta$ as well as the activation characteristics is rather poor. In a number of cases it was found that minute quantities of foreign substances and other variations which could not be detected have an appreciable effect on the activation speed and under certain circumstances activation does not take place at all. This behaviour is attributed to poisoning in analogy to the terminology used for oxide cathodes and it is necessary to investigate this poisoning effect in detail before reproducible results can be expected.

In conclusion it can be said that the requirements for the special practical application as outlined in the introduction have been fulfilled and it is hoped that this encouraging result will stimulate further systematic research work in the heretofore neglected field of secondary electron emission.

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Zusammenfassung in deutscher Sprache

Die Sekundärelektronenemission bei hohen Stromdichten mit besonderer Berücksichtigung von praktischen Anwendungen

Unter Annahme der von R. Suhrmann und W. Berger [1] postulierten Überschussmetall-Emissionszentren wird eine qualitative Theorie der Vorgänge in einer Halbleiter-Sekundäremissionskathode entwickelt. Infolge der mangelhaften Kenntnis der einzelnen Prozesse müssen vereinfachende Annahmen gemacht werden, was eine quantitative Auswertung verunmöglicht. Es wird gezeigt, dass bei einer optimalen Überschussmetall-Konzentration ein maximales Vervielfachungsverhältnis \( \delta \) erreicht wird. Während des Betriebes wird Überschussmetall infolge der Zersetzung der Sekundäremissionsstoff die erzeugt, so dass, entweder die in dieser Arbeit experimentell gefundene Bombardierungs-Aktivierung, oder der bekannte strömdichteabhängige \( \delta \)-Abfall stattfindet, je nach der herrschenden Überschussmetall-Konzentration. Durch die Einführung eines kontrollierbaren, Überschussmetall reduzierenden Prozesses, wie z. B. chemische Rekombination oder Verdampfung, kann ein dynamisches Gleichgewicht hergestellt werden, welches zu einer konstanten Emissionszentren-Konzentration und somit zu einem konstanten \( \delta \) führt. Das dynamische Gleichgewicht bewirkt eine bedeutende Verlängerung der Lebensdauer, da diese nicht mehr durch den \( \delta \)-Abfall, sondern durch die anfängliche Emissionseschichtdicke bestimmt wird, was besonders bei hohen Stromdichten von Wichtigkeit ist. Der Diffusionskoeffizient des Überschussmetall-les in der Emissionssubstanz spielt eine entscheidende Rolle betreffend dem erreichbaren \( \delta \).

Gestützt auf diese Theorie wird im experimentellen Teil eine Sekundäremissionskathode entwickelt, welche im dynamischen