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On Some Features of Electron Beam Evaporation

G. Mladenov, T. Diakov, M. Kardjiev — Bulgaria

There are at least two advantages of electron beam as an evaporator under vacuum conditions. The first one is its brightness while the second one is the direct heating of a target. By means of an electron beam it is possible to melt and to evaporate most of the refractory materials with very high speed. Unlike the resistive evaporators one can cool the crucible with evaporated substrate. All this allows to make very clean evaporated thin films. Another advantage is in the easy operation with the electron beam to achieve desired speed of evaporation and distribution of density of the steam beam. Facing the practical application, the there is very interesting region of interaction of the electron beam with the target. As a result of intensive heating appeared a zone with high pressure steam, partly ionized. In our opinion up to now, there is't any theoretical work which explains completely and uncontradictorily this phenomenon — nonequilibrium region with scale of millimeters.

In this work results of experimental investigations of electron beam evaporation with different power density — from 10^3 up to $10^6 W/cm^2$ are reported. An axial electron gun of triode type with facilities to deflect a beam up to 30^0 has been used. The acceleration voltage is 30 kV and beam currents vary up to 300 mA. The water cooled cupper crucible is located 450 mm from the gun aperture and a plate for wafers is 250 mm away from crucible. The entire vacuum chamber with a volume of 0.4 m^3 is dynamically pumped to a pressure up to 10^{-5} Torr.

Under these conditions we can distinguish three regions: the near zone, the transition region and the distant region. There is a free molecule motion in the last region as opposed to the near zone where pressure is elevated (1—100 Pa) and a high speed streams of evaporated metal are generated. One can see on Fig. 1 the dependance of evaporation speed and deposition speed versus the total power of the electron beam with stainless steel as a target. It is also very interesting to see the dependence of density of charged particles versus the electron current through the focusing coil on Fig. 2. The latter quantity defines the power density of the incident electron beam. We find nonmonotonous variation of charged particles density along with increasing power density beyond 10^7 W/cm^2. This peculiarity takes place with other materials as well, but with different values of the power density. This phenomenon may be explained as an effect of liquid phase decreasing into a cave formed by electron beam at a target surface. When the power density is under critical (10^7W/cm^2), a cave isn't formed and a material evaporation follows the law of a point source. One can consider that in the vicinity there are vapour streams with very high speed because of large gradients of pressure between the cave and the surrounding space in a vacuum chamber. The experimental reasoning of this model can be found in Fig. 3, where it is drawn the normalized deposition ratio versus angle of penetration. It can be seen a considerable difference from Knudsen model of evaporation which leads to a cosine law for the distribution of deposition ratio.

As we have mentioned earlier, the vapour streams are partially ionized. Because of that the distribution of charged and neutral particles are very similar. On Fig. 4 it

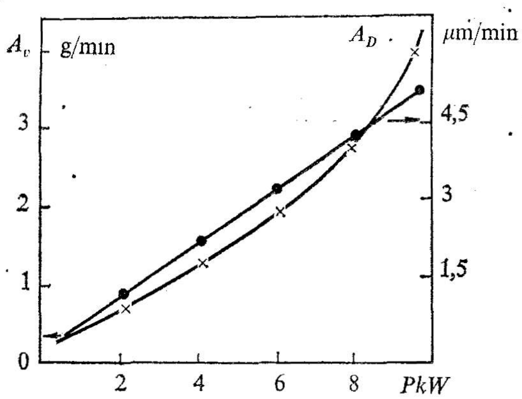

Fig. 1. Evaporation speed (left) and deposition speed (right) versus total power of electron gun, target — stainless steel

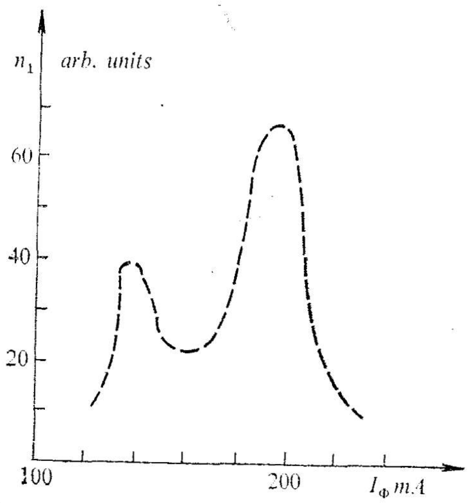

Fig. 2. Charged particles density versus current through focusing coil of the electron gun. Evaporation of Al, $P=10$ kW

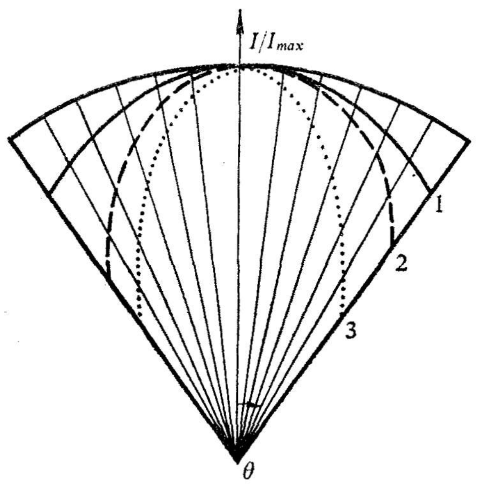

Fig. 3. Normalized ratio of deposition (Al) versus angle of deposition. Power density of the electron beam :
1—6.10^5 W/cm^2; 2—10^6W/cm^2; 3—5.10^6W/cm^2

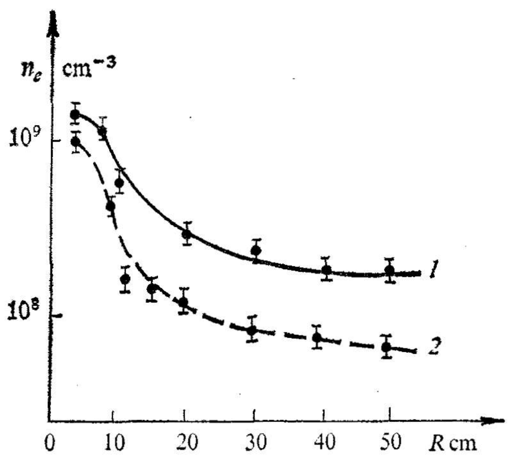

Fig. 4. Charged particles density versus distance into a vacuum chamber. Evaporation of Al,$P=10^6 W/cm^2$

can be seen a typical space distribution of charged particles density within the vacuum chamber. There exist three regions: near, transition and distant. The similarity of the space distribution behaviour of charged and neutral particles allows us to monitor the process by simple and reliable electron probes. This is a clear advantage comparing to the more elaborate, complex and expensive methods, usualy used for monitoring neutral fluxes.

In conclusion it can be stated, that our experience permits to control via ion current the evaporation of stainless steel, aluminium, copper and molibdenum by means of the electron beam with power density below the critical value. In this way we can achieve very elevated speed of evaporation without decreasing the high quality of deposited thin films.

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