THIN LAYER DEPOSITION UNDER HIGH ENERGY METAL IONS BOMBARDMENT

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Abstract

A new type of discharge which is generating in vacuum partly ionized metal vapors can produce ions with energies outpassing 100 eV. The relation of ions energy on plasma parameters is described. High quality can be obtained for the thin film growing under bombardment of own metal ions. High value of thin film peeling force is obtained for the metal thin film deposited on plastics.

Thin metal layer deposited using thermal evaporation presents voids, the physical properties like density, reflectivity, resistivity, etc. of such layer being quite different from those of the bulk metal. Heating of the sample during deposition can improve these properties but in such cases a tendency for large size polycrystalline structure growing is promoted /1/.

Bombardment of the thin layer during its growing by accelerated noble gas ions exceeding 100 eV energy can ensure high quality of the deposited thin film.

This technology usually needs a separate noble gas plasma source and a continuous consumption of high purity gas /2/. Besides, as recently reported parts of the bombarding noble gas ions, are burried in the volume of the metal thin layer /3/.

In this paper we present a new type of metal layer deposition using Thermoionic Vacuum Arc (TVA) discharge. Such a discharge is established in vacuum between a heated cathode and an anode which continuously generates metal vapors just in the interelectrodic space, ensuring enough metal atoms density, to sustain the arc current. Anode material is evaporated due to the accelerated and electrostatically focused electron beam on anode surface, a high voltage being applied across the electrode. A bright discharge appears and the established metal vapor plasma which is continuously expanding in the vacuum chamber, away from the TVA plasma source /4/ - /8/. A high current arc in the vapors of the anode material using a cold cathode has been obtained and extensively studied by Universität Essen Team /9/ - /12/. Most of the processes taking place in these two type of discharges are similar. Typical volt-ampere (V-A) characteristics of the TVA discharge is shown in fig. 1 which was obtained for a given electrodes geometry and cathode temperature. At high currents over 20 A, this characteristics is similar to that one corresponding to the cold cathode anodic vacuum arc.

The heated cathode being at earth potential the ions will have an energy related to the plasma potential. It is abvious that for an arc voltage drop of 70 V, no ions will have an energies outpassing 20 eV. In fact their energy will have a value less than 20 eV. It results that if we need high energy ions we must have high voltage drop accross the arc. Such low current and high voltage arc can be sustained only with a heated cathode arc, i.e., TVA as we can see in fig. 1. The working point change on arc characteristic given in fig. 1 is easily possible even with arc in running condition. Consequently, for high deposition rate we will shift toward high current low voltage side of the characheteristics and if we need high energy of ions we can chose a working point at high voltage and low current range of characteristics.

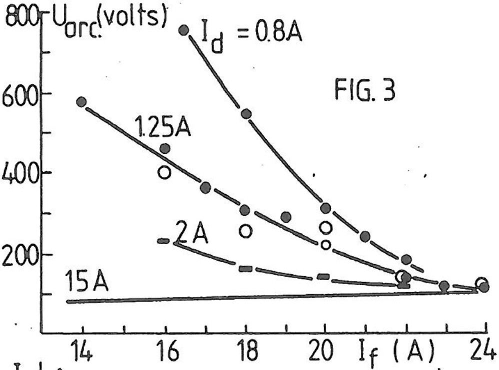
Experimental measurements of the energy of ions

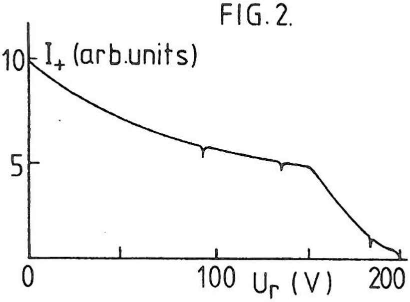
We measured ion energy using a retarding potential probe method developed at Universität Essen. For such measurement it was necessary a very good screening of the ions probe system which is located inside of the expanding metal vapor, at 250 mm away from TVA. Special attention as mentioned in /9/ - /12/ was paid to the entrance grid mesh of the ion probe. The condition to separate ions from the plasma is $\lambda_D > d$ here λ_D is Debye length and d the size of the grid holes. With these precautions, due to the fact that TVA is a quiet discharge, the ion current characteristic can be recorded. In fig. 2 is given such a characteristics which represents the ion current passing the grid and arriving to the collector which has a positive potential and is repelling the ions. As we can see, in the peculiar case represented by fig. 3, only repelling voltages much higher than 100 V can stop the ions.

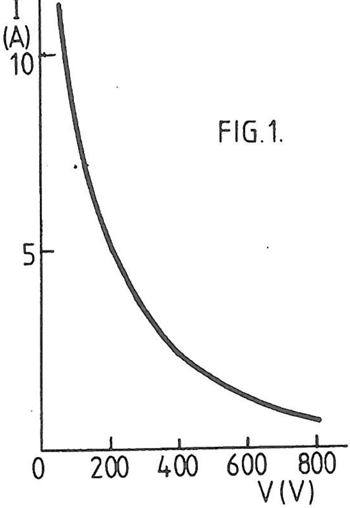
We must point out that the end side shape of the curve given in fig. 2 is due to the energy distribution of ions.

Extended studies have shown the parameters on which the ions energy depends. Mainly, the energy of ions will depend on the metal vapor plasma potential against the heated cathode. This potential will depend on arc voltage drop namely on the working point on volt-ampere characteristics (see fig. 1). At high voltages over the TVA, corresponds higher energy of ions.

However, at high voltage drops curresponds low arc currents which means a low value of the flux of metal ions. The volt-ampere characteristics can be shifted for a constant arc current to higher voltages decreasing the cathode temperature (i.e. the density of







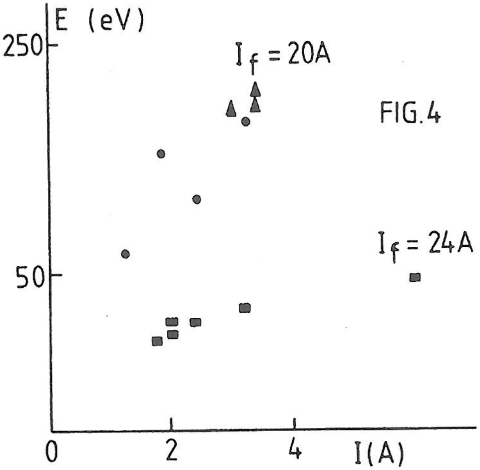


Fig. 1 Volt-ampere characteristics of Thermoionic Vacuum Arc (TVA).

Fig. 2 Ion current distribution versus repelling potential of ion collector.

Fig. 3 Dependence of the arc voltage drop on the cathode heating current.

Fig. 4 Measured ion energy dependence on discharge current for two different values of cathode heating current.

thermoelectronic current) or changing the geometry of electrodes in such a way that interaction of the eletron beam with evaporating anode is made more difficult. This can be easily obtained for example increasing cathode - anode distance or changing the angle of the electron beam incident on anode surface up to 90^0.

In fig. 3 is given the dependence of the arc voltage drop on the cathode heating current I_f (i.e., cathode temperature) for various discharge currents. In choosing the convenient parameters to obtain a needed value for the energy of ions of TVA, attention must be paid to the fact that percentage of ion flux (number of ions/number of ions and neutrals incident on sample surface, depends on the discharge current. At low arc current this value (of the order of 1 - 3 A) can be of the order of 3 - 5%, outpassing 20 - 30% at high currents 20 - 100 A).

Consequently, in increasing the arc voltage drop it is necessary to not decrease the ion flux under a limit value, characteristic for a given technological process. In fig. 4 is given the measured ions energy dependence on arc current for a geometry of cathode anode with $\varphi = 85^0$ and for two values of the cathode heating current.

The results given in fig. 4 and 5 clearly prove the strong dependence of ions energy on arc voltage drop as well as the fact that an easy way to generate ions with an established energy is possible. The analysis of SEM images with 2.10^4 magnification have shown compact structure of cross section and a smorth surface of the deposited thin layer.

However, we must point out that any spurious discharge in residual gas in vacuum vessel at bad vacuum conditions (pressure toward 10^{-4} torr) drastically drop the energy of ions.

During various thin film depositions, we observed in some conditions appearance of droplets. In order to study such cases, we used close distance between sample and TVA plasma source (50 mm). In this case we observed an unexpected "shaping" of the droplets due to the energetic own material ion bombardment.

Thin film deposition on plastics using TVA

Copper thin film has been deposited on plastic material using TVA. Because the adderance of such films is one of the most important parameters, we paid a special attention to this parameters. Usually in order to increase the adderence, a previous discharge in a gas mixture of oxigen and argon is necessary to prepare the plastic surface before copper layer deposition.

We used in our experiment direct deposition of copper on plastic without any previous treatment expecting to have a good adderence due to energetic ions bombardement the plastic surface. Indeed the obtained results confirmed our expectation and after electrochemical deposition of a 35 μm copper layer on 1 μm TVA deposited copper thin film, values of the peeling forces up to 1 kg/cm have been observed.

The obtained values of the peeling forces were clearly dependent on the energy of ions, increasing with ion energy.

Most probably only first few layers of metal film on plastic surface must be deposited using high energy ions TVA discharge (which has low deposition rate). After this layer, the discharge can be of shifted smoothly (without stopping it) along the volt-ampere characteristic towards high current low voltage arc with rate deposition outpassing 50 nm/s.

Conclusion

Thermoionic Vacuum Arc (TVA) appear to be a convenient discharge for metal layer depossition on various surfaces ensuring the bombardment of the growing thin film with own energetic ions.

Using TVA, established values of the energy of metal ions can be ensured and high adherence of deposited thin layer obtained.

Besides, this type of discharge open a way for new solid state material (including alloys preparation) growing under the bombardment of energetic ions.

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