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THERMOIONIC VACUUM ARC (TVA) - ONE OF THE BEST SUITABLE METHOD FOR HIGH PURITY COMPACT SMOOTH THIN FILMS DEPOSITION

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Описаний метод термойонної вакуумної дуги (ТВД) як новий найбільш придатний метод для осадження тонких плівок високої чистоти з компактною структурою та дуже гладких, який зручний для отримання плівок із наноструктурою. ТВД може генерувати джерело плазми чистих металів всередині вакуумної камери (включаючи високовольтні умови), забезпечуючи ефективне іонне бомбардування плівки, що наноситься, атомами матеріалу, який наноситься. Енергія іонів повністю контролюється і навіть може змінюватися протягом осадження. Описана також можливість нанесення тонких плівок вуглецю, ці плівки цілком вільні від водню.

Описан метод термоионной вакуумной дуги (ТВД) как новый наиболее подходящий метод для осаждения тонких пленок высокой чистоты с компактной структурой и очень гладких, удобный для получения пленок с наноструктурой. ТВД может производить источник плазмы чистых металлов внутри вакуумной камеры (включая высоковольтные условия), обеспечивая эффективную ионную бомбардировку наносимой пленки атомами напыляемого материала. Энергия ионов полностью контролируется и даже может изменяться в течение осаждения. Описана также возможность нанесения тонких пленок углерода, эти пленки полностью свободны от водорода.

Thermionic Vacuum Arc (TVA) is described as a new very suitable for deposition of high purity thin films with compact structure and extremely smooth, just convenient for nanostructure film realization. TVA can generate pure metal vapor plasma source inside of a vacuumed vessel (including H. V. conditions), ensuring energetic ions bombardment of the just depositing material own atoms of the condensing film. The energy of ions can be fully controlled and changed even during deposition. Possibility of condense the carbon thin films is also described, these films being completely hydrogen free.

Extended studies on thermionic vacuum arc has been performed during past ten years in the form of a successful bilateral cooperation between Romanian and German team [l-5].

The main advantages of this new method are:

- deposition of pure metal film in high or ultra- high vacuum conditions;
- no gas consumption;
- thin film is condensing from the plasma of the evaporating metal or compound;
- the growing thin film is bombarded just during deposition with the ions of the depositing material avoiding any gas inclusion in the film and insuring a compact film (no columnar structure);
- the energy of bombarding ions can be controlled at will and even changed during deposition;
- the surface of the deposited film is smooth, the TVA technology being a good candidate for nanostructure (thin film deposition technology);
- no micro - particles in the deposited thin film;
- low heat transfer from plasma source to the sample because at high vacuum conditions the heat transfer is due only to the e.m. radiation;
- quite high deposition rate.

Experimental arrangement

In figure 1 is given schematically the experimental arrangements used to produce thermionic vacuum arc:

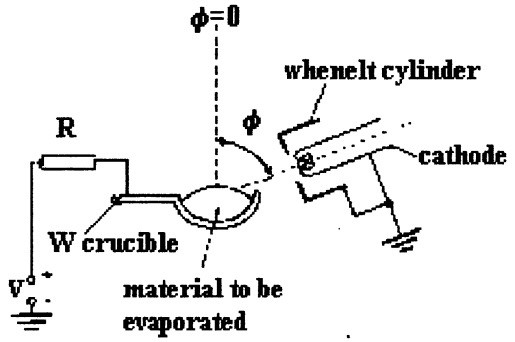

Fig.1. The experimental arrangements used to produce thermionic vacuum arc

The material to be evaporated (solid particles of mm. size) is filling the anode. (A) is a spoon like tungsten crucible. The cathode (C) is a tungsten filament (wire diameter 0,5…0,8 mm) which is mounted inside a molybdenum whenelt cylinder having a front hole with a diameter of 5…6 mm. This assembly is mounted inside of a vacuum vessel. The cathode is grounded and a high voltage is applied via a resistor to anode (crucible).

ВОПРОСЫ АТОМНОЙ НАУКИ И ТЕХНИКИ. 2002. №1.
Серия: Вакуум, чистые материалы, сверхпроводники (12), с.169-171.

There are two main geometrical working parameters namely the relative cathode - anode position given by interelectrodic distance *d* and the *0* angle between whenelt cylinder axis and the imaginary vertical line passing through tungsten crucible center.

The sample is usually positioned on vertical line at a distance *D* from the anode.

TVA ignition

In order to ignite the thermionic vacuum in arc, in the vacuum vessel, pressure must be lower then lO torr.

The filament of the cathode is heated at high temperature in order to have a significant termo-electronic emission. An adjustable (d. c.) high voltage V is applied over cathode - anode space. Due to the incident power on anode, (the product VI, where I is the discharge current), the material from the crucible starts to melt and then to boil. A steady state density of atoms (of the evaporating material) is established in the interelectrodic gap. At further increase of the applied high voltage (V), a heated cathode arc in the vapors generated from anode is established. We will call this necessary voltage as breakdown voltage of TVA. In fact, this ignition is different from the well - known breakdown of luminescent discharge. Indeed in the case of TVA, the applied voltage is ensuring also the gas (in this case metal vapors) necessary to support discharge current. Moreover, just after ignition the steady state density of the evaporated atoms from the anode **must be maintained**, in spite of the fact that part of the voltage is lost on ballast resistor and on the plasma potential drop. Otherwise, just after ignition, the discharges extinguish the process of ignition being periodically repeated. We may say that the breakdown voltage to ignite TVA must fulfill the following conditions:

- to ensure enough density of evaporated atoms in the interelectrodic space;
- to generate using thermoelectrons enough ions per second to have a charge multiplication of metal vapor plasma or compound plasma and generation;
- after ignition must maintain at least the same rate of atom evaporation from the anode.

Because the evaporation rate must be proportional with the power dissipated at the anode, the rate before ignition is proportional with V-L After ignition, a plasma is established in the interelectrodic space the passing current being l_{arc}. The power at anode level will be $l_{arc}\cdot U_{anode}$ potential drop. So the last condition can be written:

$$I_{thermoelectronic}\cdot V = I_{arc}\cdot U_{anode\ potential\ drop.}.$$

The plasma of the termionic vacuum arc

The studies of the TVA plasma have been performed mainly using metal as evaporating material from the anode. In this case, the plasma generation is easier because of low energy levels of the metal atoms. In addition, plasma density is quite high.

It results that the plasma potential drop is low, the applied high voltage being practically divided between cathode fall and anode fall. In Fig. 2 is given the assumed potential distribution in the TVA.

As we can see from figure two plasma is at a potential Vc against the ground because cathode is grounded. In fact, the plasma produced steadily in the interelectrodic space is continuously expanding away from its source. We measured plasma potential against the cathode starting nearby plasma using the electric probe source in the direction of the expanding plasma. The results show that plasma potential is steadily decreasing. It results that in this potential decrease we have an electric field accelerating the ions towards the sample. Therefore, at 250 mm distance from the source, metal ions are incident on substrate surface with high energy. Both plasma parameters (charge density, electron temperature) as well as ion energy and ion flux has been previously reported by our team. The measurements using ion energy analyses have proved that at convenient conditions, the energy of ions in TVA can achieve values of 250…300 eV.

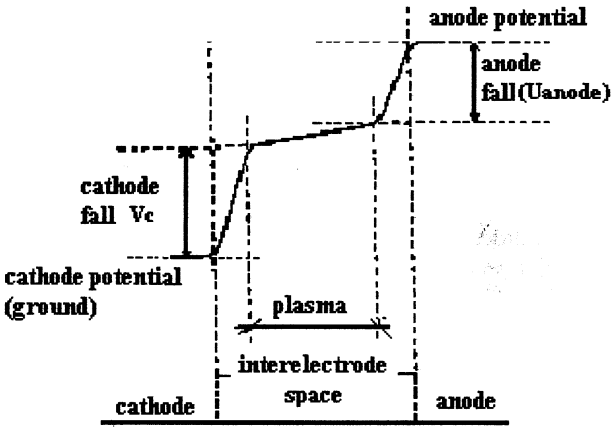

Fig.2. The assumed potential distribution in the TVA

The control of the energy of ions in TVA using the working parameters

Before describing the simple method to adjust at will the energy of ions even during deposition we must stress from the very beginning the importance of energetic ion bombardment of sample during deposition. Indeed, a large number of papers have stressed the strong relation between deposited thin films quality and the process of bombarding the layer during deposition with energetic ions. Due to the impact of energetic ions, the deposited atoms are rearranged and the film processed in this way is more compact, without voids having proprieties close to the bulk metal. Also, the thin film surface is very smooth. In many experiments, the growing metal film is bombarded with noble gas ions (for example in magnetron sputtering) but in this case, noble gas atoms are trapped inside of thin films. In the case of thermionic vacuum arcs, the film is bombarded with the ions of the just deposed material. Both compactness and smoothness of the films are obtained if the energy of ions is over a critical value. It results that we need a technology that permits to adjust the value of the energy of ions any time during deposition process.

Let us return to figure 2. We can see that we must control in fact the value of the energy of ions through the cathode potential fall. Indeed the potential of the plasma against the ground (i. e. vacuum vessel wall and also cathode) is just equal with cathode potential fall.

Performed measurement has showed that very low energy value for ions are obtained if the thermoeleiptronic current source is close to the plasma. This is the situation when (p = 0 and d = 2…3 mm (see figure 1). If the electron source is away from the plasma, for example <p = 80°, d = 4…5 mm, the cathode fall is high because in order to have the same arc current, highest voltage must be applied to get a convenient cathode fall, able to collect electrons. Similar effect is obtained if for (p = 30° the distance d) is increased to 6…8 mm.

Moreover, extended studies on various working conditions have provided finally that between voltage drop, U_{plasma}, over entire discharge and measured energy of ions, E_{ions}, there is a simple relation:

$$E_{ions} = k \cdot U_{plasma}.,$$

where k is a constant usually between 0,2…0,35. In this way, the energy of ions can be easily adjusted at a known value only changing the applied voltage. At this stage, it is worthwhile to say that the increased ion energy proved out to decrease the deposited lower roughness as shown in figure 3. The AFM measured roughness is given against the ions directed energy, E_{ions}, represented through V_{plasma} when MgO layers were deposited by TVA technology.

In fact, in order to increase the energy of ions, it is necessary to make difficult to get enough electrons from the cathode, arriving to the anode. Of course we checked successfully other methods like the decrease of the heating current of the cathode (very efficient but shortening the cathode lifetime) decreasing the whenelt cylinder front hole or changing the position of the cathode (filament) inside of the whenelt cylinder.

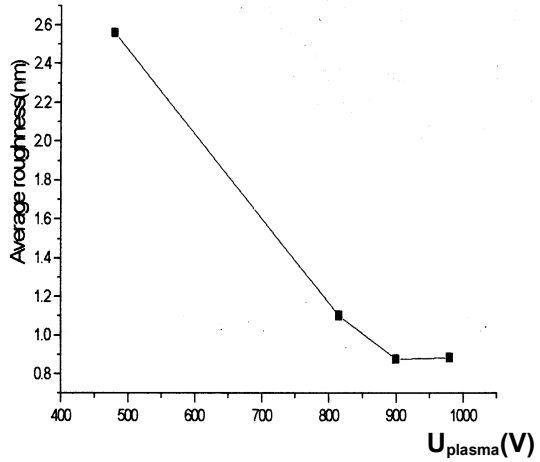

Fig.3. The ion energy versus average roughness

Hydrogen free carbon thin film deposition

An increased interest is paid today to hydrogen free carbon film deposition the aim being diamond like layer production with low friction, increased hardness, etc.

Because of the elevated temperature for carbon sublimation (>4000K), in most of the laboratories, the carbon films have been obtained using plasma chemical technologies. In all such experiments, the obtained carbon film contains incorporated hydrogen atoms.

Three methods have been used up today to produce hydrogen free carbon layer, namely filtered carbon arc in vacuum, mass - separated carbon ion beam or pulsed laser deposition through carbon ablation.

Thermionic vacuum arc has been considered by us as a possible candidate for such deposition because it is not difficult to heat the carbon rod by the accelerated electrons to temperatures higher than 4600K. Also, the optimum value of energy of carbon ions 70…80 eV necessary to obtain sp3 bound carbon films [6] can be easily obtained and due to high vacuum condition, hydrogen presence is avoided when TVA is used.

In figure 4 is shown a simplified view of the used experimental arrangement:

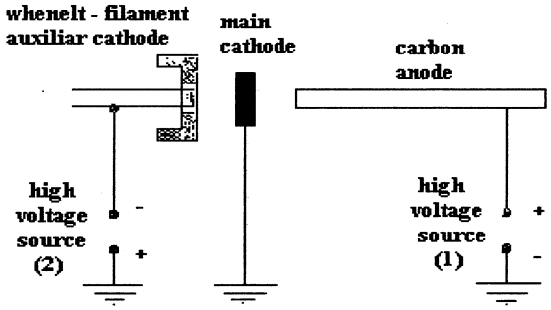

Fig.4. The experimental arrangement

Conclusions

The developed system for thin film deposition using thermionic vacuum arc (TVA) is a very promising one both to obtain high quality of the film and extreme purity.

In order to avoid any suspicion of crucible material contamination of metal vapor plasma when very high purity film must be obtain, we generated using TVA vapor plasma just as a spot on bulk material surface simultaneously cooling the bulk material (spot TVA evaporation).

Because of large number of parameters directly controlling the film quality, TVA will be soon considered as one of the best systems to produce thin films for nanostructures.

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