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Al_2O_3 THIN FILM DEPOSITION USING THERMIONIC VACUUM ARC

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ABSTRACT

The thermionic vacuum arc (TVA) is a new technique for the deposition of thin metallic and nonmetallic films. TVA discharge is established in vacuum between a heated cathode (a tungsten filament) and an anode (a tungsten crucible filled with Al_2O_3 pellets). TVA discharges in Al_2O_3 vapors were generated and thin Al_2O_3 films were deposited on the glass substrates using TVA. The surfaces of thin Al_2O_3 films were examined using a Metallurgical Optical Microscope (MOM) and Scanning Electron Microscope (SEM). Al_2O_3 thin films have been analyzed using X-ray diffraction (XRD) method.
Keywords: Plasma, Thermionic vacuum arc, Al_2O_3 thin film deposition.

TERMİYONİK VAKUM ARK KULLANARAK AL_2O_3 İNCE FİLM DEPOLAMA

ÖZET

Termiyonik Vakum Ark (TVA), ince metal ve metal olmayan filmlerin depolanması için yeni bir tekniktir. TVA deşarj, vakum içinde ısıtılmış bir katot (tungsten flament) ve anot (Al_2O_3 parçacıkları ile dolu tungsten pota) arasında meydana gelir. Al_2O_3 buharlarında TVA deşarjlar üretildi ve ince Al_2O_3 filmleri cam tabanlar üzerine TVA kullanılarak depolanıldı. İnce Al_2O_3 filmlerin yüzeyleri Metalurjik Optik Mikroskop (MOM) ve Taramalı Elektron Mikroskobu ile analiz edildi. Al_2O_3 ince filmleri X-ışını difraksiyon metodu ile incelenildi.
Anahtar Sözcükler: Plazma, Termiyonik vakum ark, Al_2O_3 ince film depolama.

1. INTRODUCTION

Al_2O_3 is a widely used electrical insulating material. This is due to its high electrical breakdown field, its large bandgap, and its high dielectric constant. Al_2O_3 is a hard material and has a very high melting temperature and excellent chemical stability. Al_2O_3 depositions in various forms are used in semiconductor devices [1-3], refractory, antireflection and anticorrosive coatings [4], and capacitance humidity sensors [5]. These films have been prepared by various techniques such as chemical vapor deposition (CVD) [6], metal organic chemical vapor deposition (MOCVD), [1, 3], spray pyrolysis [7], thermal evaporation [8], sputtering [9], etc.

The thermionic vacuum arc (TVA) is a new technique for the deposition of thin metallic and nonmetallic films. TVA thin films are obtained as a result of heated cathode discharge

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established in vacuum condition in the vapors of the material to be deposited [10, 11]. MgO thin film deposition [12] and carbon deposition [13] using TVA have been reported. A TVA system at Osmangazi University in the year of 2000 was constructed [14]. The aim of this paper is to present the preliminary results of Al_2O_3 TVA depositions.

2. EXPERIMENTAL DEVICE

The TVA consist of a directly heated cathode, which is a tungsten filament mounted inside a molybdenum Wehnelt cylinder, and an anode which is a tungsten crucible containing the materials to be evaporated. A photograph of the cathode used in the present experiment is shown in Fig. 1.

Figure 1. Photo of the cathode showing the filament placed inside the Wehnelt

The two electrodes are mounted on a table which is placed in the center of a vacuum cylindrical stainless steel chamber having a volume of 65 lt. A schematic presentation of the TVA electrode arrangement for an interelectrode angle $0^o < \varphi < 90^o$ is shown in Fig. 2.

The vacuum was obtained by a conventional pumping system, which consists of a rotary pump with a capacity of 1.027 lt/s, and a diffusion pump with a capacity of 135 lt/s. The pressure was measured by an active pirani gauge with range of atmosphere to 10^{-3} mbar and an active inverted magnetron gauge with range of 10^{-2} to 10^{-9} mbar connected to an active gauge controller. The electrical system consists of two power supplies (low voltage and high voltage), a voltmeter (0-1800V), an ammeter (0-2A), and a ballast resistor (300Ω).

The thermoelectrons emitted by the cathode are focalized by the Wehnelt cylinder, and accelerated toward the anode containing the material to be evaporated (Al_2O_3 pellets) by the applying high voltage. The accelerated electron beam, incident on the anode, heats the crucible together with its content to high temperature, Al_2O_3 starts to evaporate and a steady state density of the evaporated Al_2O_3 is established in the interelectrodic space. For a convenient density of Al_2O_3 molecules and decomposed atoms and a needed value of the applied voltage, a thermionic vacuum arc discharge is established in pure Al_2O_3 vapors. Al_2O_3 thin film depositions are obtained as a result of TVA discharge established in the vapors of Al_2O_3.

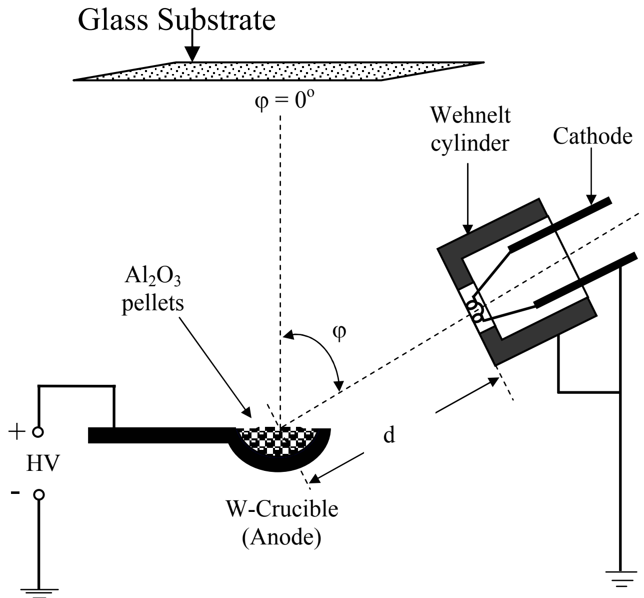


Figure 2. Schematic diagram of the TVA electrodes arrangement for $\varphi > 0^o$. "HV" indicates the high voltage power supply. The electrodes can be arranged in various relative angular positions "φ" and distances "d" to the anode

3. RESULTS

The volt-ampere characteristic of the Al_2O_3 TVA discharge which is generated in condition that cathode filament heating current I_f=16A, interelectrodic angle φ=50° and interelectrodic distance d=6mm is given in Fig. 3.

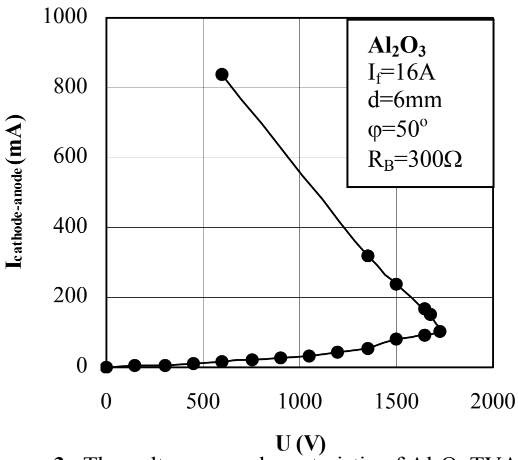


Figure 3. The volt-ampere characteristic of Al_2O_3 TVA discharge

As seen in Fig. 3, at the beginning, the characteristics are identical with those of vacuum diodes, but at an increased value of the applied voltage a sudden jump of the current is observed, simultaneously with the ignition in vacuum conditions of a bright Al_2O_3 TVA discharge between electrodes. The ignited arc current for fixed electrode geometry and fixed cathode heating current is constant as can be seen in the volt-ampere characteristic of Al_2O_3 TVA discharge. If the cathode filament heating current increases in the ignited arc, ignited arc current increases. This variation obtained in ignited Al_2O_3 TVA discharge is given in Fig. 4. Dependence of the ignited arc current of Al_2O_3 TVA discharge on the filament current is similar to dependence of that of the metal vapor TVA discharges on the filament current. This is important because TVA discharge can be controlled by the filament current.

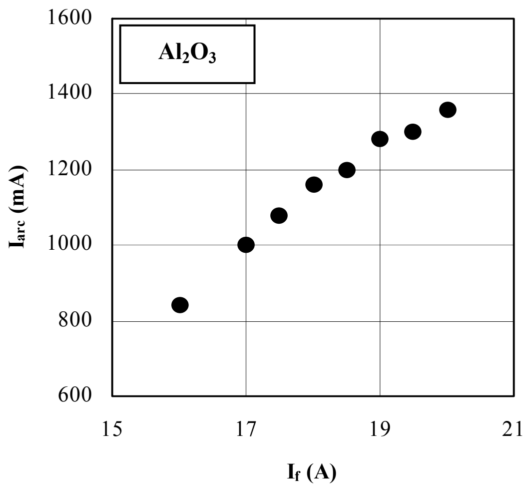
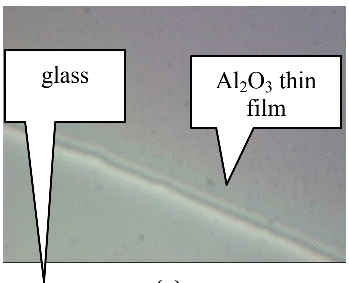
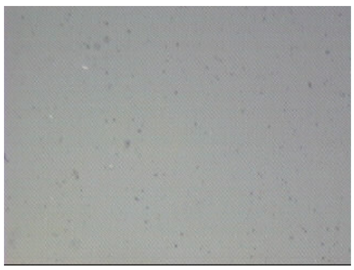


Figure 4. Dependence of the ignited arc current on cathode filament heating current

The thin films of Al_2O_3 have been deposited on the glass substrates of 10x20 mm size with a thickness of 1mm. The surfaces of the deposited Al_2O_3 thin films were analyzed by a MOM. MOM images obtained various points of our samples are given in Fig. 5.



(a)



(b)

Figure 5. (a) MOM image of border of glass- Al_2O_3 thin film, **(b)** MOM image of midpoint of Al_2O_3 thin film

The surface morphologies given to Fig. 5 prove the smoothness of our Al_2O_3 thin films. Black points on the micrographs belong the glass surfaces as can be seen in Fig. 5a. MOM images of various points of our sample and the samples deposited various discharge currents are similar to Fig. 5. Also the smoothness of the Al_2O_3 layer is proved by the obtained SEM images given in Fig. 6.

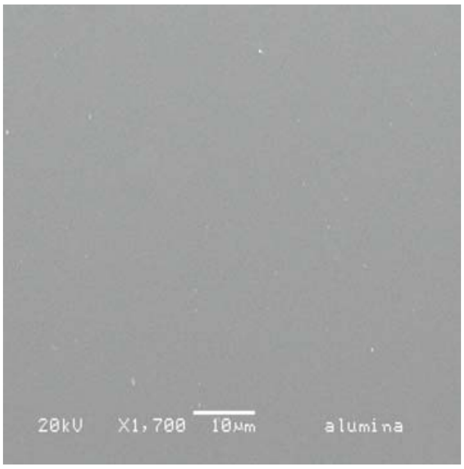


Figure 6. SEM photograph of the Al_2O_3 deposited film

Thin Al_2O_3 films were analyzed by X-ray diffraction (XRD) method. XRD analysis result of an Al_2O_3 films are presented in Fig. 7.

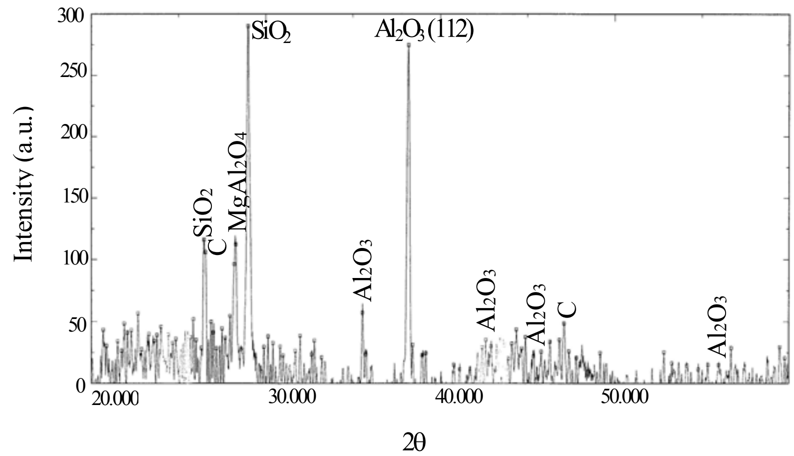


Figure 7. X-ray diffraction spectrum of the Al_2O_3 thin film.

The XRD spectrum of the Al_2O_3 thin film shows the dominant orientation is (112). The TVA discharge produces energetic neutral atoms besides energetic ions with directed energies. The energy of ions can be controlled by TVA voltage drop [15] and changed at will even during deposition, achieving even more than 400 eV [14]. This means that on the substrate arrive not only the evaporated neutral atoms but also incident energetic ions. As a result of this peculiarity of TVA, SiO_2 and $MgAl_2O_4$ peaks in the XRD spectrum given in Fig. 7 could be due to influence of Al_2O_3 ions with glass substrate. The use of pure substrate like Si should be important. Carbon impurities come from the residual diffusion pump oil vapors decomposed in plasma conditions.

4. CONCLUSIONS

The discharges of Al_2O_3 can be produced using the TVA. The TVA discharges of Al_2O_3 can be controlled by cathode filament current as the TVA discharges of metals. Thin Al_2O_3 films were obtained using TVA technique. MOM and SEM images of Al_2O_3 thin films show the films are smooth. The XRD measurements show the dominant orientation of Al_2O_3 is (112).

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