Boron processes using thermionic vacuum arc

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Boron is one of the most difficult materials to process because of its high melting and boiling temperature. Thermionic Vacuum Arc (TVA) is an externally heated cathode arc which can be established in high vacuum condition, in vapors of the anode material. The TVA has proved to be a highly efficient method for producing droplet-free plasmas in metal vapors where electron bombardment results in the efficient target heating and subsequent evaporation at the anode, with vaporization temperatures of over 3000 K. In this paper, boron evaporation property before TVA ignition and XPS analyses of boron thin film deposited by TVA are presented.

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1. Introduction

Boron processes are important technologies recently considered to be of special interest due to the qualities of boron. Although boron has long been used in many technologies like glass and ceramic, cleaning and bleaching, flame retardant, agriculture, health, semiconductor, energy, etc., metallurgical research on the element itself is relatively recent. The reason for this delay is probably the high temperature required for the production of the element from its compounds, and the great reactivity of boron at these temperatures. The Thermionic Vacuum Arc (TVA) generates a pure, gas and macroparticle-free metal plasma. Due to its unique properties this discharge enables a simple control of important process parameters like the degree of ionization, deposition rate and ion energy [1-4]. Such important advantages relevant to the specific application of high-temperature resistant films include the following: no gas precursors or carrier gases needed, deposition of films of high melting temperature materials such as carbon, cobalt, rhenium, tungsten, boron and chromium [5-8]. Present paper concern the TVA in boron vapors, its evaporation property before TVA ignition and XPS results of boron thin film.

2. Experimental

The TVA discharge is ignited under vacuum conditions between a heated cathode emitting thermoelectrons and an anode containing the material to be evaporated. As cathode is used a simple electron beam gun, which consist from a tungsten filament mounted inside of a Wehnelt cylinder. The anode is a carbon crucible, filled up with particles of the material to be evaporated - in the present experiment boron (Fig. 1). The electrodes assembly is mounted in a vacuum vessel (end pressure is 10^{-6} torr). In Fig. 2 is shown a photo image of the electrodes, the anode being a carbon crucible on which is lying a boron particle.

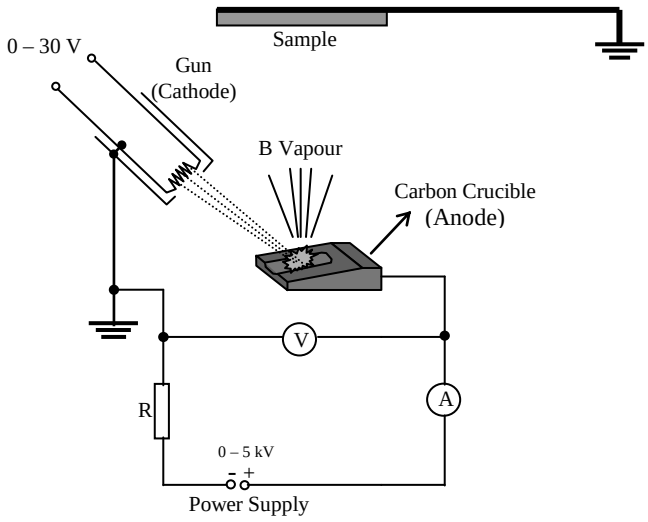

Fig. 1. TVA electrodes arrangement.

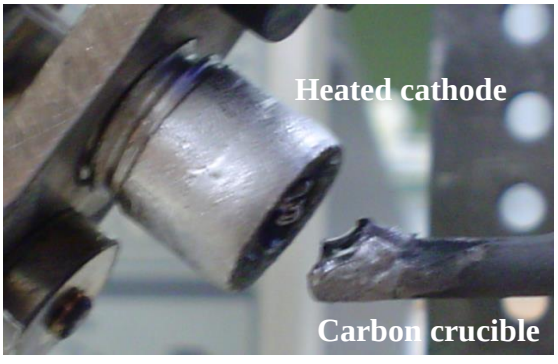

Fig. 2. The photograph of electrodes of TVA system for boron processes.

The electrical system consists of two power supplies, a voltmeter, an ammeter, and a ballast resistor (500Ω). An a.c. variable low voltage power supply with maximum value of 1kW, 0-27V was used to heat the cathode and a d.c. variable high voltage power supply with maximum value of 10kW, 0-5kV was used to accelerate the electrons from the cathode to the anode.

Due to the electron bombardment of the anode by the accelerated thermo-electrons from the grounded cathode towards the anode (which is at high voltage), anode material pieces first melt and then start to vaporize, creating a steady-state concentration of the evaporated atoms in the cathode-anode space. With a further increase of the applied high voltage, a bright discharge is established inside of the vacuum vessel in the anode material vapours.

In Fig. 3 is shown the volt-ampere characteristics of TVA using boron as anode material. The negative slope of the volt-ampere characteristics corresponds to TVA discharges. Voltages up to 4000 V are used to ignite and to maintain the boron TVA discharge. Due to the high melting (~ 2300^{o}C) and high boiling (~ 3900^{o}C) temperature of boron, the high voltages are necessary in order to ignite the TVA discharges in the vapors of the boron. The temperature of carbon crucible rises to at least the melting point of boron before the ignition. For comparison in Fig. 3 is given the volt-ampere characteristics of copper (low melting point material) TVA discharges.

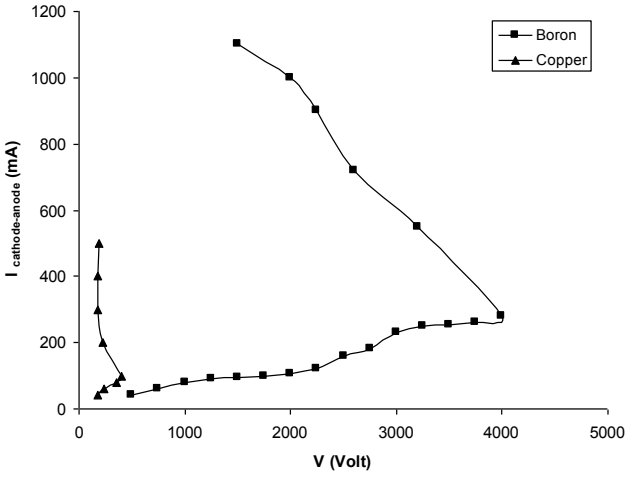

Fig. 3. The volt-ampere characteristics of TVA discharges of copper and boron. Cathode heating current is 22A.

In Fig. 4 is shown the pressure distribution of boron evaporation before boron TVA discharge ignition. For comparison in Fig. 4 is given pressure distribution of copper evaporation before copper TVA discharge. Due to the electron bombardment of the boron start to vaporize like copper. However, with a further increase of the applied high voltage, while copper evaporates linearly, boron evaporates exponentially. This property of boron evaporation before ignition is different from observed previous metal TVA processes like copper [9]. Boron is absorbing the gas in the vacuum vessel, and this property can be used for other material TVA processes to establish ultra high vacuum.

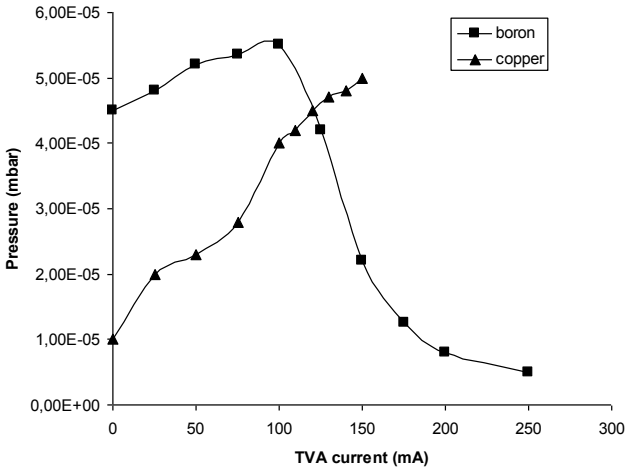

Fig. 4. The pressure distribution of boron and copper evaporation before TVA ignition.

The boron thin films were obtained using a Thermionic Vacuum Arc (TVA) ignited and maintained in the vapors of boron generated at the anode. At high TVA currents, as a result of boron vapor interaction with the tungsten cathode, the cathode's filament is destroyed in time. However, an acceptable duration of the boron vapors arc discharge is obtained (up to 45 s) to establish experimental points. The rate of boron film deposition on the level of glass substrates was up to 200nm/min. The glass substrates were mounted at a vertical distance of 100 mm from the TVA discharge. In Fig 5 is given, X-ray photoelectron spectroscopy (XPS) analyses of boron thin film deposited glass substrate using TVA. As can be seen in Fig 5, boron, oxygen, nitrogen, and carbon were determined in the boron thin film. Carbon is coming from carbon crucible and oxygen and nitrogen is coming atmospheric conditions because boron thin film is inserted in air conditions before XPS analyses.

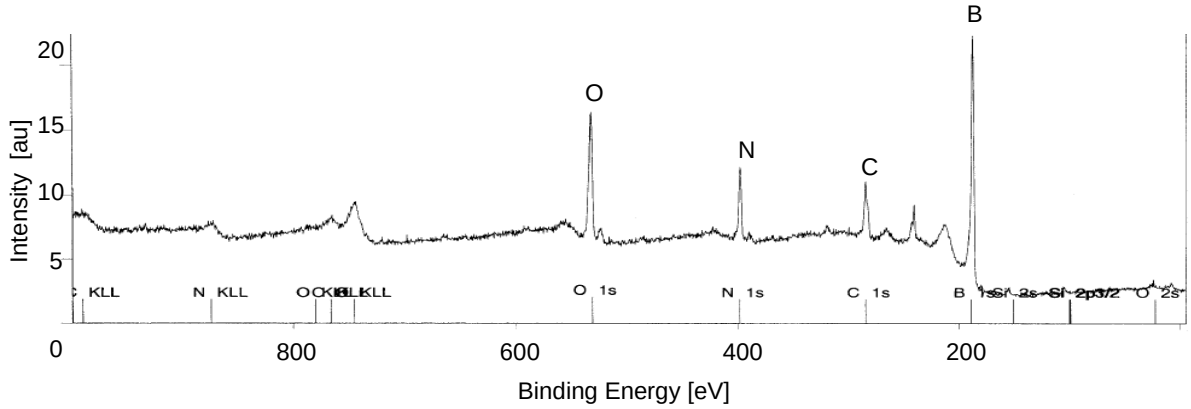

Fig. 5. XPS analyses of boron thin film deposited by TVA method.

3. Conclusion

Boron was processed successfully using TVA. Pressure distribution of boron processed by TVA is different from many metals like copper. The results demonstrate that the TVA system is a promising method in refractory materials processing like boron.

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