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Grid emission suppression characteristics of molybdenum grids coated with Hf and Pt films

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Abstract

Hf and Pt were deposited onto molybdenum grids by ion beam-assisted deposition (IBAD). Electron emission characteristics from these coated molybdenum grids contaminated by active electron emission substances (Ba, BaO) of the cathode were measured using the analogous diode method. X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) were performed on the surface of molybdenum grids coated with Hf and Pt films. When emission substances were deposited onto the grid surface, the reaction between BaO and Hf formed a $BaHfO_3$ compound that markedly reduced the accumulation of BaO and accordingly decreased grid emission. The decomposition of BaO on the surface of Pt under high temperature was believed to lead to the formation of Ba and its re-evaporation from the surface, reducing active electron emission substances with a consequent significant reduction in grid emission. According to the comparison of their grid emission suppression mechanisms, it could be concluded that grid emission suppression was mainly the reduction of active electron emission substances on the grid surface, in particular BaO. This could be a worthwhile approach for the development of new grid coating materials.

Keywords: Electron emission; Molybdenum grid; Platinum; Hafnium

1. Introduction

Pulsed-controlled grid traveling wave tubes (TWTs) are widely used in the field of space and defense for navigation and directing of radars, aircrafts, satellites and guided missiles. Advantages of typical TWTs include high gain, high power, wide working frequency band, small volume, light weight and high reliability. In order to reach ever-higher frequency and power requirements needed for the current demands of modern information society, gun designs for current microwave tubes have utilized grids, which are very close in proximity, or are actually bonded directly to the cathode. Unfortunately, a harmful electron emission from the grid, termed grid emission, is often observed owing to the deposition of the active electron emission substances (Ba, BaO) from the cathode during the device lifetime, which may destroy the working condition of the TWTs. Hence, it is essential to maintain the non-emitting properties (i.e. high work function) of the grid surface.

High work function refractory metals such as Mo, Ta, W, Zr, Hf, etc. [1,2] are frequently used for non-emitting grids. Pyrolytic graphite with an ability to dissipate heat and suitable electrical properties is the only non-metallic material that has been widely applied in grids [2]. Consequently, the development of suitable anti-emission coating materials is of considerable practical importance. Liu et al. [3,4] reported that carbon films deposited onto the surface of molybdenum grids by ion beam-assisted deposition (IBAD) had achieved remarkable results. Molybdenum grids coated with Al films by vacuum ion deposition technology can restrain effectually grid emission owing to the formation of $Al_{13}Ba_7$ compounds during the grid work process [5]. The intermetallic coating of Pt_3Zr [6],

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titanium silicide, $TiSi_2$, and the mixture of Zr and graphite [7,8] have been used widely as anti-emission coating materials too.

Many patents described different anti-emission materials, but none of them is universally applicable [7]. Very little is quantitatively known about their anti-emission characteristics and surface composition under high temperature. In this paper, we deposited Hf and Pt films on the surface of molybdenum grids using the IBAD method. The grid electron emission characteristics were measured using the analogous diode method and the grid surfaces were analyzed using X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS). From a comparison of possible grid emission suppression mechanisms, a new approach to the development of grid-coating materials was proposed.

2. Experimental

Pt films were deposited onto molybdenum grids using the IBAD technique. While Pt was sputtered by the ion beam, the depositing film was simultaneously bombarded by Ar^+ ions with energy in a range from 30 to 90 keV. The deposited film thickness was about 300 nm. Hf films were deposited onto molybdenum grids using an EATON-200 ion beam mixing system. While Hf was vaporized by an e-beam gun, the depositing film was bombarded by Xe^+ ions with energy in a range from 30 to 90 keV. The film thickness in this case was about 500 nm.

The schematic diagram of the test vacuum diode is shown in Fig. 1. The anodes are a pure molybdenum grid, and molybdenum grids coated with Hf and Pt films. The cathode is a typical impregnated Ba–W cathode material ($4BaO \cdot CaO \cdot Al_2O_3$). The distance between them is less than 1 mm. Both the grid and the cathode with the diameter of 1 cm are all heater type. After installation, air exhaustion, excitation and packaging, the vacuum of the test diode was less than 10^{-4} Pa. In order to maintain a high degree of vacuum, an adsorbent was fixed within the structure of the test diode. The cathode was heated to about 950 °C and the grid was kept at about 780 °C during the course of testing; this would ensure that sufficient emission substances (Ba, BaO) from the cathode deposited onto the opposite grid to simulate an actual working environment of TWTs. *I–V* characteristic curves were measured during the testing procedure. The surface phases of the grids were identified using the D/max 2550 V X-ray diffractometer with an accuracy better than 0.002°. The chemical states for the surface elements on the surfaces of molybdenum grids coated with Hf and Pt films were analyzed using the XSAM800 XPS instrument.

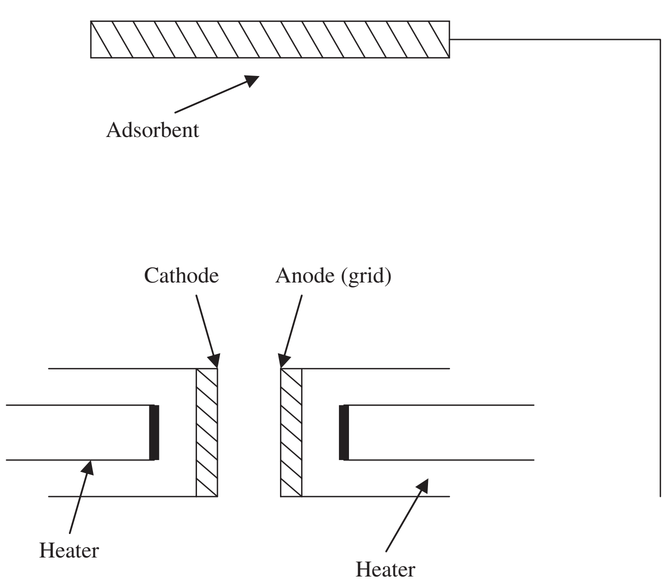

Fig. 1. Schematic diagram of the test vacuum diode.

3. Experimental results and discussion

3.1. Characteristic curve of the test vacuum diode

The original *I–V* curves of the test diode are listed in Fig. 2, showing that emission currents increase with the applied voltage and that the emission current of a pure molybdenum grid is higher than that of molybdenum grids coated with Hf and Pt films. Narita's investigation [9] showed that work functions of Mo substrates, where BaO had been deposited for 6 and 60 min when Mo substrate temperature was kept at 800 °C, were 2.2 and 1.85 eV, respectively. In the present experiments, a degree of BaO and Ba were inevitably deposited on the surfaces of the grids during the active operation of the cathode. This could lower the work function of their surfaces significantly and the emission current of a pure molybdenum grid is much higher than that of molybdenum grids coated with Hf and Pt films.

Emission currents of molybdenum grids coated with Hf and Pt films as a function of time during the testing are shown in Fig. 3. The emission currents were from the

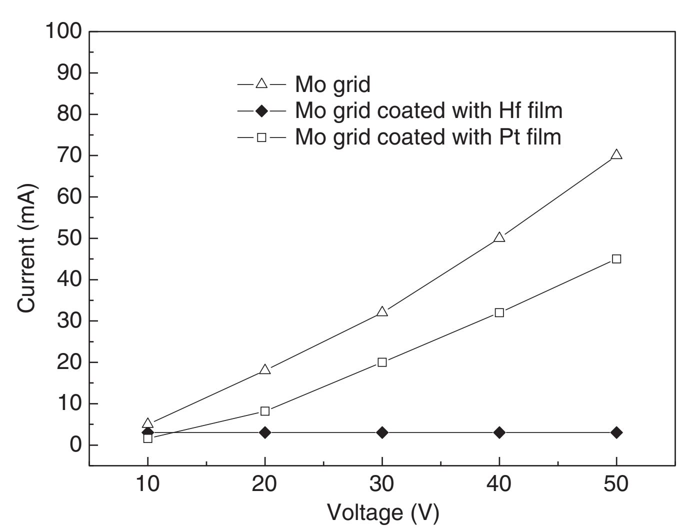

Fig. 2. The original *I–V* curves of the test diode before the testing.