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Control over the emission properties of impregnated dispenser cathodes via surface pore density

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ABSTRACT

Metal injection molding (MIM) was used to fabricate impregnated dispenser cathodes. The emission properties of tungsten cathodes were adjusted by controlling the number of exposed surface pores via mechanical polishing after completion of the impregnation process with $4BaO:CaO:Al_2O_3$ (4:1:1) at 1600 ~ 1900°C. The average distance between neighboring pores decreased as the number of pores increased. Three cathode samples having various surface pore densities were compared. Emission improved as the surface pore density increased. An average distance between exposed pores of 3.32 μm resulted in an emission current of 2.14 A (7.57 A/cm^2) at 1030°C_{br}, corresponding to a work function of 1.92 eV, which is comparable to that of an M-type cathode. Thus, control of the surface pore density of impregnated cathodes provides a simple, cost-effective means to produce high current density thermionic electron guns.

1. Introduction

All typical vacuum electron sources require a good quality electron beam to generate high-power microwaves. It is well known that a porous metal matrix can act as an electron reservoir and the diffusion layer of the emitting material provides a low work function for the surface of the porous metal matrix [1–5]. At present, thermionic dispenser cathodes are most widely used as high-power microwave sources. A typical dispenser cathode consists of a sintered porous tungsten (W) skeleton (density: 74 ~ 86%) and an electron emissive material, commonly called the 'impregnant', usually BaO, CaO, and Al_2O_3 [3–7]. The porous W skeleton has traditionally been produced as follows: die pressing of the well-blended W powder, sintering at a high temperature, infiltration of pure copper or synthetic resin, machining to a suitable shape, and removal of the infiltrated copper or synthetic resin. After that, the impregnant is melted into the pores of the W skeleton in a hydrogen or inert atmosphere. Finally, the impregnated W cathode is cleaned with boiling water to remove excess surface impregnant. There are, however, some drawbacks to this process. High inter-particle friction and poor packing by the die-pressing technique result in a non-uniform pore distribution. This inhibits smooth supply of the barium to the cathode surface and adversely affects the emission characteristics of the cathode. The infiltration of pure copper or synthetic resin for machining can also cause contamination of the cathode and consequently leads to degradation in its performance.

In this study, to prevent these problems and enhance emission, metal injection molding (MIM) was used for cathode fabrication [8–10]. MIM is considered to be an efficient, cost-effective technique. MIM also offers several advantages including the ability to form complex shapes, tight tolerances, and material selection of metals and ceramics. The MIM technique does not require much machining after completion because the shape is determined by the use of a mold. Surface machining alone is required to fit the exact dimensions after impregnation. Because the pores on the cathode surface are crushed in this process, the cathode will eventually need to be polished to expose the pores once again. In this study, we were able to control the number of open surface pores according to the amount of polishing, while retaining channels inside the cathode. On measurement of the emission current of various cathodes with different numbers of surface pores, our results showed higher emission currents for cathode surfaces having a greater number of pores. It is well known that the average diffusion distance of the Ba atom on the cathode surface affects the ability to maintain Ba surface coverage and that the work function depends on Ba coverage [3,4,6,11]. We were able to enhance the emission property of the dispenser cathode by controlling the

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average distance between neighboring pores. Using several surface analysis techniques, including scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and X-ray photoelectron spectroscopy (XPS), we determined the optimum average diffusion distance of the Ba atom for the low work function of a typical dispenser cathode.

2. Fabrication

The MIM process is divided into four key steps: mixing, injection molding, debinding, and sintering [8–10]. It is important to note that the uniformity of the W matrix depends on the grain size. In this work, W powders in the range of 4–5 μm (average 4.5 μm) were used. The 'feedstock' was produced by mixing the W powder with a polymer binder. Injection molding of the uniform W powder and binder was then performed by means of a mold prepared in advance. The binder was removed with a solvent and thermal debinding to obtain binder-free 'brown parts'. The brown parts were sintered in a furnace at 1800 ~ 2200°C for 20 min ~ 2 h in a hydrogen atmosphere. Fig. 1 shows a comparison of the porosity of the resulting W billets produced using MIM (Fig. 1 (a,b)) and die-pressing (Fig. 1(c,d)). Fig. 1(b) shows more smaller and uniform pores than those in Fig. 1(d). These results suggest that the MIM technique is more effective at producing pores for impregnated cathodes.

A sintered W matrix with a porosity of 20% was impregnated with barium-calcium-aluminates in a molar ratio of 4BaO:-$CaO:Al_2O_3$ (4:1:1) at 1600 ~ 1900°C. This is termed the Philips type 'S', currently the most widely used cathode type [3]. After impregnation, the W billet was machined into a cylinder (radius: 3 mm; height: 6 mm); the emitted current form the cylindrical samples were measured using an in-house manufactured emission test bench. Since the MIM technique is originally used to create a particular condition using a shaped mold, it is not easy to establish a fixed shape with a specific porosity via sintering. Therefore, it was necessary to rework it along the base design after sintering and impregnation. The next step in the fabrication process was mechanical polishing to expose the impregnated pores on the surface of the cathode. During this process, the number of surface pores could be adjusted in the observable range. The average distance between neighboring surface pores decreased as the surface pore density increased. The residue of the impregnants on the cathode surface was finally removed by boiling water, and the cathode samples were fired in a furnace at 900°C for 20 minute after polishing. Impregnated cathodes of varying pore density were compared: Sample1 (high pore density: 6.68%), Sample2 (medium pore density: 4.32%), and Sample3 (low pore density: 2.24%).

3. Results and discussion

3.1. Emission property

The emission properties of three fabricated cathode samples varying in surface pore density were measured in a custom-designed ultra high vacuum system with an easily replaceable test unit that consisted of a focus electrode, anode, heater and heat shield [12]. This test unit comprised an electron gun-shaped anode and a focus electrode, as well as a separate Faraday cup for collecting the emission current, as shown in Fig.2. The gun configuration allowed measurement of high current over a long time, as well as easy replacement of the cathode. The test unit was manufactured to test a cylindrical cathode (radius: 3 mm; height: 6 mm) and could be used to measure a maximum current density of 25 A/cm^2 due to the structural parameter of perveance.

The cathode temperature, in degrees centigrade brightness (°C_{br}), was measured on the surface of the hot cathode using a disappearing-filament optical pyrometer via the vacuum chamber window. Before measurement, all cathodes were activated at 1200°C_{br} for 1 h Fig. 3 shows the measured emission currents of the three cathode samples of differing surface pore density for a high voltage pulse of width 5 μs at 1029 ~ 1031°C_{br}.

The Sample1 cathode provided a much higher emission current (green line) than the others (Fig. 3). Because Sample1 had the largest number of pores, it exhibited better activation than the other samples, as a result, a higher current density of 7.57 A/cm^2; the corresponding work function was 1.92 eV, based on the Richardson-Dushman equation [1,2,6]. Compared with a typical Philips type 'S' (4:1:1) cathode, which has a work function of approximately 2.1 eV [3,4,6,11,14], the Sample1 cathode provided a low work function and good emission properties. It is comparable

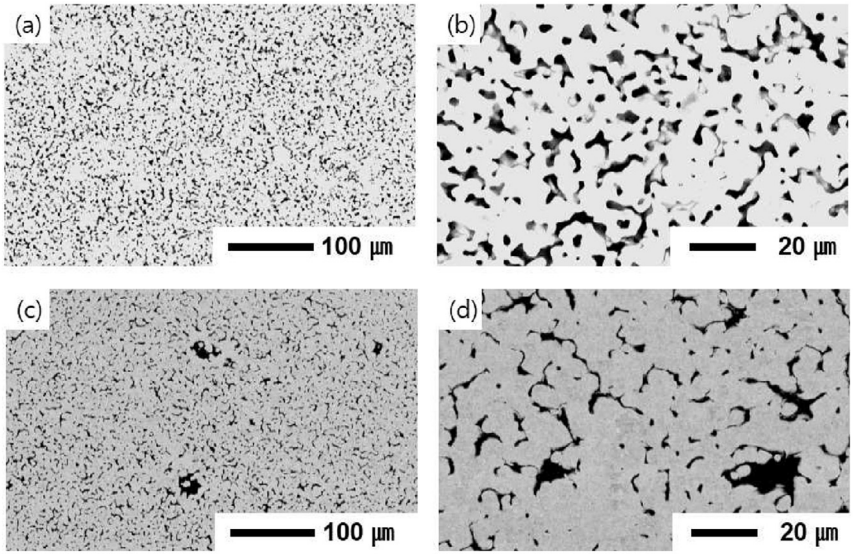

Fig. 1. Scanning electron microscopy (SEM) images of the sintered tungsten (W) billet: (a) sample created using metal injection molding (MIM) (500×), (b) an enlarged MIM sample (2000×), (c) sample created using die pressing (500×), and (d) enlarged die-pressed sample (2000×).