INVESTIGATIONS OF THE FIELD EMISSION CURRENT FROM BISMUTH CERAMIC CATHODES

Bolesław Mazurek, Jan Ziaja, Maciej Noras

Institute of Fundamentals Electrotechnics and Electrotechnology, Technical University of Wrocław,
pl. Grunwaldzki 13,
50-377 Wrocław, Poland

ABSTRACT

In this work the investigations of the emission current from $Bi_2Sr_2Ba_2Cu_3O_x$ and $Bi_2Sr_2BaCu_2O_x$ ceramic cathodes are presented. Experiments were carried out in the vacuum chamber at pressure within the range of 10^{-8} Tr (10^{-6} Pa), with DC high-voltage power supply and high-class digital electrometer. Current-voltage and Fowler-Nordheim characteristics for the cathodes superconducting in liquid nitrogen temperature were obtained for various distances between electrodes. Current vs. temperature characteristics were also measured. For some measurements the transparent anode technique was employed in order to provide informations about emission origin point. Emission current was registered for the electron emission originating from a single emission center.Superconducting state did not influence current-voltage dependences. It was observed for superconducting cathodes that emission current abruptly changes in the vicinity of the superconducting transition temperature T_c. Emission current was stable and practically constant for the temperatures below T_c and became unstable and noisy for the temperatures above T_c. Emission current rate depends on the temperature range of the superconducting transition ΔT_c.. Superconducting parameters of the cathodes: critical temperature T_c, temperature range of the superconducting transition ΔT_c and critical current density j_c were also measured. It was found that sorbtion phenomena on the surface of cathodes during cooling and heating of the electrodes influence emission current values and play major role in the emission phenomena.

1. INTRODUCTION

High-T_C superconductors find a growing interest in technics. A lot of new materials showing better and better superconducting parameters are still being developed. Among devices and systems based on high-temperature superconductors there are many applications that work under high electric field conditions, for instance high-voltage transmission lines [1] and radio frequency cavities [2]. So there is a need to investigate behavior of these materials under high-electric field stresses. The physical nature of the emission phenomena observed on the superconducting materials surfaces has not been clearly described so far. To achieve a part of this goal some experiments were carried out. In this paper the results of measurements of the field emission current from $Bi_2Sr_2Ba_2Cu_3O_X$ and $Bi_2Sr_2BaCu_2O_X$ cathodes are presented. Those were measured for the electron emission originating from a single emission point, that was observed on the transparent anodes.

2. PROCEDURE

2.1 System

The setup for field emission current measurements consisted of vacuum chamber, vacuum pumps, system of electrodes with externally cooled cathode, high-voltage DC supply and electrometer. After the cathode was mounted, the vacuum chamber was evacuated up to the pressure of 10^{-8} Tr (10^{-6} Pa). Measurements of the emission current for some of the specimens employed "transparent anode" technique in order to provide information about emission origin point. Transparent anodes were glass discs coated with tin oxide layer.

2.2 Cathodes

Bismuth ceramics used in investigations were obtained in the reaction in the solid state. Cathodes were the discs of 2 cm in diameter and 3-4 mm thick. Phase composition investigations indicate that in the first stage of sintering the $Bi_2Sr_2BaCu_2O_X$ phase is formed. As the time of sintering in high temperature is prolonged, the $Bi_2Sr_2Ba_2Cu_3O_X$ phase is formed. The percentage fraction of both phases influences the superconducting parameters of the cathodes. Cathodes were carefully cleaned before mounting in the vacuum chamber. Ultrasonic cleaning removed part of the contaminations from the surfaces of specimens. The material contrast photography

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taken by means of electron microscope shows us contaminations left on the cathode surface. Two experiments were carried out in order to remove contaminations from the surfaces of the cathodes. The first one was storage of the cathodes in the vacuum of 10^{-4} Tr (10^{-2} Pa), in room temperature (27°C) and in 500°C conditions. After this treatment the superconducting parameters of specimens were deteriorated. An X-ray photography of samples indicated that heating caused deoxidation of the bismuth ceramic. In the second experiment the surfaces of the cathodes were cleaned by glow discharge in the argon atmosphere. As in the first experiment the superconducting parameters were decayed. These experiments demonstrated that such a conditioning of the bismuth ceramic cathodes is ruled out due to chemical decomposition of the cathodes.

3. EMISSION CURRENT MEASUREMENTS

3.1 Current-voltage characteristics

Measurements of the field emission current dependences on voltage applied were carried out in two temperatures: 300 K (27°C) and 77 K (- 196 °C). The voltage was gradually increased (curves 1 in fig. 1) till the emission current reached the order of magnitude 10^{-7} A and then the voltage was decreased (curves 2 in fig. 1). As the first the measurement in the temperature of 77 K was carried out. The specimens chosen for measurements varied with theirs superconducting properties. In fig. 1 the dependence between the emission current and voltage typical of bismuth ceramic cathodes are presented. They are drawn in log(I)=f(U) and Fowler-Nordheim ($\log(I/U^2)=f(1/U)$) coordinates. In both cases the curves are hysteresis. For the cathodes cooled to the 77 K temperature the higher voltage should be applied in order to initiate the field emission than for cathodes in room temperature. In both temperatures there are linear fragments of curves and if voltage increases, curves become saturated.

3.2 Current-temperature characteristics

Emission current vs. temperature measurements were carried out during step-by-step cathode heating from the temperature of 77 K to the level above critical temperature of the superconducting transition T_c. Voltage was fixed at the value for which the emission current was measurable. The current value should not be so high because of possible electrical breakdown in the space between electrodes during the cathode heating. In fig. 2. The dependences of typical resistance (a) and emission current (b) on temperature are presented for bismuth ceramic cathodes. The abrupt jump in emission current values in the vicinity of superconducting transition temperature T_c was observed. For the cathode consisting of two superconducting phases ($Bi_2Sr_2Ba_2Cu_3O_x$ and $Bi_2Sr_2BaCu_2O_x$, - that was confirmed by the X-ray photography), with two different superconducting transition temperatures, double emission current jump was noticed (region A in fig. 3.). Simultaneously the change of the emission site took place - that was observed on the transparent anode. In fig. 3. anode is marked as the black circle with the emission site inside. Field emission current is practically stable for the temperature below critical temperature T_c and become noisy and unstable for the temperature above this critical value.

4. DISCUSSION

The character of the emission phenomena depends on the state of the cathode surface: - presence of the oxide layers, microstructure of the surface, presence of the gases adsorbed. Existence of these intrusions was confirmed by the electron microscopy observations. It was shown that conditioning and cleaning of the cathodes surfaces in the vacuum conditions result in the chemical decomposition of the bismuth ceramic. Because of these facts it can be assumed that gaseous sorbtion and desorbtion phenomena play major role in the emission processes. Storage of the cathodes in the vacuum results in liberation of certain fraction of gaseous particles that are present on the cathode surface. Presence of the electric field is accompanied by degassing processes. On the other hand some particles come from the inside of the vacuum chamber and sediment on the electrodes. The lower the temperature of the cathode is, the higher theirs sorbtion abilities are. For the systems non-conditioned by heating - as in this case - 50 % of gases adsorbed on the surfaces of the cathodes is the steam [3]. Cooling of the cathode to the temperature of the liquid nitrogen results in solidification of the ice and in adsorbtion of the gas layer on the specimen surface. Such a mixed layer acts as a dielectric layer. So we can assume that cathode is coated with an insulator. Several emission mechanisms were proposed for such an electrode system. Among these models are Shkuratov [4], antenna [5] and Latham and Mazurek [6] mechanisms. It can be assumed that cathodes made of high-T_c superconductor are well described by the above mentioned electrode-insulator-vacuum system. It is proved that emission phenomena are strictly dependent on the space and surface charge induced by an electric field. This charge is formed from gases desorbed and ionised. Charge is also induced in the non-conducting particles (impurities) present on the

cathode surface. The next aspect of the emissive properties the irregularity of the cathode surface is. Because of this the electric field is not homogenous; in the neighbourhood of the micropoint tips the electric field is enhanced. Such a tip can become an emission center. The charge is present on the cathode surface and in the space around the emission center. The dependences of the field emission current on voltage applied form the curves of the hysteresis shape. Similar results are presented in literature for the non-superconducting metal cathodes [6, 7]. This hysteresis effect observed in the measurement cycles can be explained by the charge neutralisation and surface charge outlet from the emission center area. Field emission current vs. temperature measurements confirm that state of the surface influences the emission phenomena in the case of the high-T_c ceramic superconductors. In the temperature below critical temperature T_c emission current flows from the emitter without losses of energy. Current flow density must be below critical current density j_c value. If not, the emission center will loose superconducting properties and then current flow will start to produce heat inside emitter. As the temperature is raised, emitter becomes non-superconducting in the vicinity of the critical temperature T_c. The gas particles adsorbed in the nearest enclosure of the emission point are desorbed and come into the region between electrodes. Above T_c value the pressure of gases increases in the regions of desorbtion and the impact ionisation takes place. In consequence the positive space charge is formed in the vicinity of the cathode. It results in local electric field enhancement in the emitter region and the emission current increases. The space charge reduces the region of ionisation, and the creation of ions is terminated. This charge screen effect limits the emission current flow. A cloud of positive ions and remaining electrons can be swept by an external electric field and the cycle is repeated. In this way, based on the mechanism described by Latham and Mazurek [6], it is possible to explain abrupt jump in emission current values in the vicinity of the critical temperature T_c when the cathode is heated, and instabilities of the emission current above T_c. Such a jump of current is not observed for the cathodes made of superconducting ceramic that is non-superconducting in the liquid nitrogen temperature 77 K [7]. For the cathodes consisting of two phases: $Bi_2Sr_2Ba_2Cu_3O_x$ and $Bi_2Sr_2BaCu_2O_x$, with two different superconducting transition temperatures, current jump was noticed for both T_c temperatures. Emission current flow influences cathode surface state. Electrons flow from the emission centers present on the surface. Exceeding the critical current flow density j_c limit results in the loss of superconducting state of the emission center. Then the temperature of emitter increases and chemical decomposition can take place. In the extremal case the emitter can be evaporated. Point X-ray photography of the cathode surface after evaporation of the emission center indicates that the chemical decomposition of the emitter area took place.

5. CONCLUSIONS

Critical parameters of the cathodes obtained from the superconducting $Bi_2Sr_2Ba_2Cu_3O_x$ and $Bi_2Sr_2BaCu_2O_x$ ceramics depend on the technological parameters, i.e.: pressure of forming, temperature and time of sintering. The structure of the cathodes was controlled by an X-ray photography analysis and electron microscopy observations. It was found that cathode conditioning causes chemical decomposition of the specimens. Based on the results of measurements it can be inferred that superconducting state does not influence the character of the field electron emission from bismuth ceramic cathodes. Emission originated for lower voltage in room temperature than in 77 K temperature, but the shape of characteristics was similar in both cases. Non-superconducting metal cathodes show similar behavior [6,7]. Sorbtion phenomena on the surface of the cathodes during the cooling and heating of the electrodes essentially influence emission phenomena. Current-temperature characteristics indicate that emission current flow is very stable for the cathodes in the superconducting state. Above critical temperature T_c an abrupt jump in emission current values occurs and current flow becomes unstable. For the cathode consisting of two phases with two different critical temperatures T_c double current jump appears.

6. ACKNOWLEDGEMENTS

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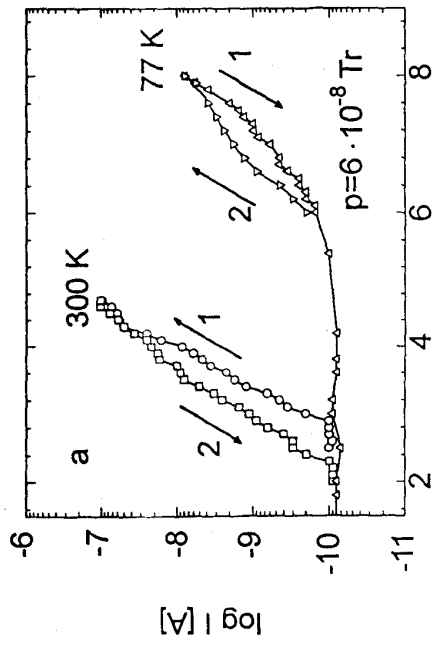

Fig. 1. Typical current-voltage characteristics for the bismuth ceramic cathode superconducting in the liquid natrium temperature. T_c=105 K, j_c=142 A/cm^2:a) log (I)=f(U) coordinates, b) Fowler-Nordheim coordinates. Distance between electrodes 1 mm.

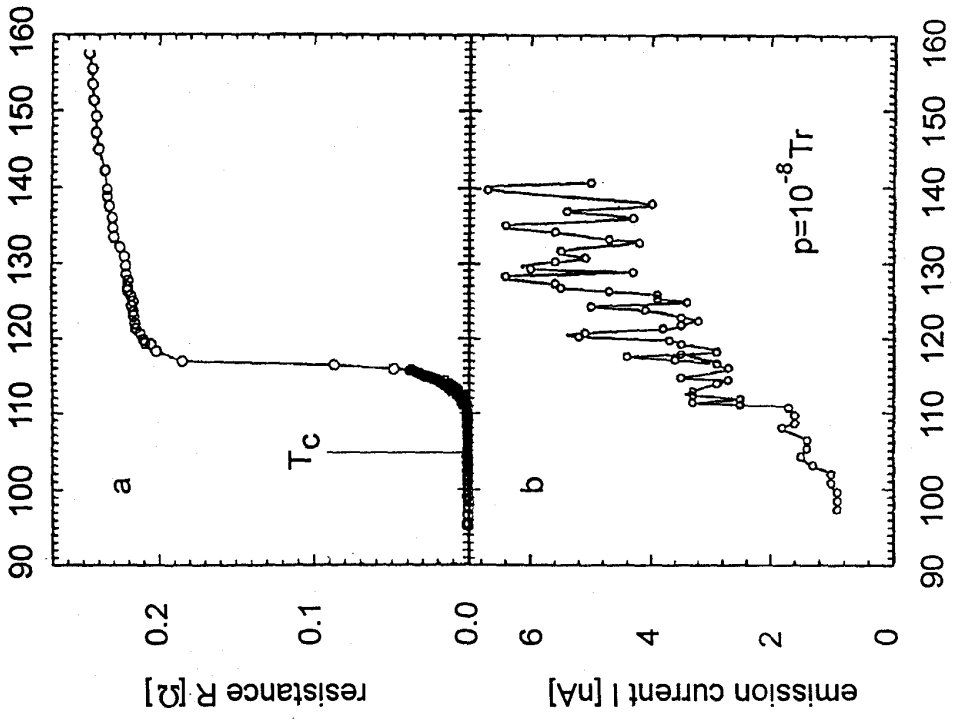

Fig. 2. Typical resistance (a) and emission current (b) vs. temperature for the bismuth ceramic cathode superconducting in the liquid natrium temperature T_c=105 K, ΔT_c=10 K, j_c=128 A/cm^2.

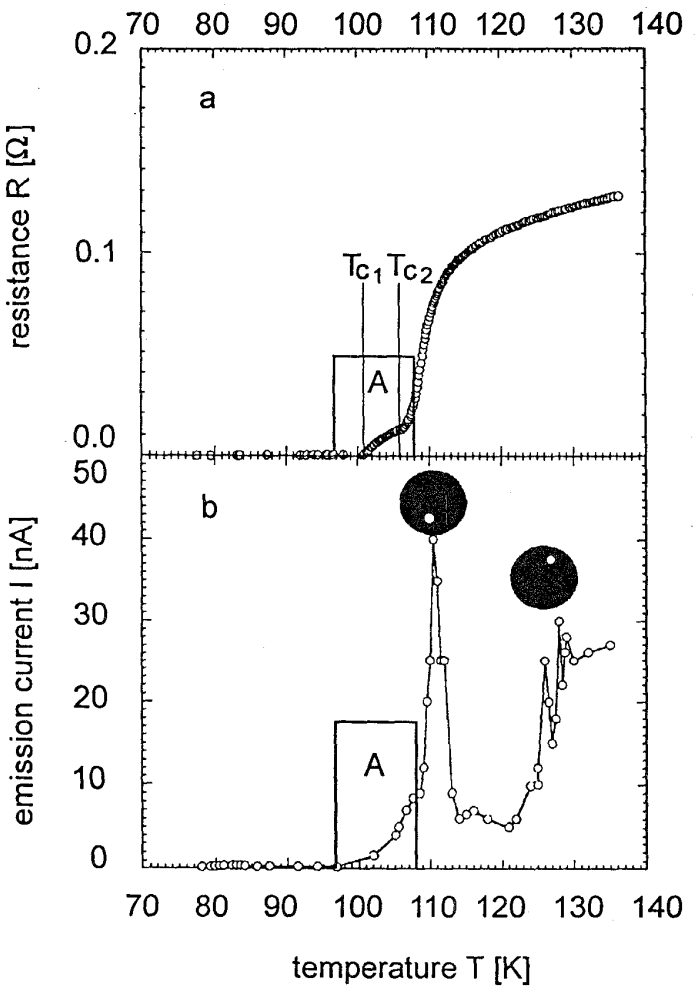

Fig. 3. Resistance (a) and emission current (b) vs. temperature for the bismuth ceramic cathode consisting of two phases: .$Bi_2Sr_2Ba_2Cu_3O_x$ and $Bi_2Sr_2BaCu_2O_x$. T_{c1}=101 K, T_{c2}=108 K. Black circles are transparent anodes with emission sites marked inside. Region A is the region of the double current jump.