The 8th Symp. on Accelerator Science and Technology, 1991, Saitama, Japan

MATERIAL SEARCH FOR THE ANODE ELECTRODE OF 1.2MW CW KLYSTRONS

M. Yoshida, S. Isagawa and S. Yoshimoto
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan

Abstract

Several 1.2MW klystrons (E3786) delivered for TRISTAN had a problem of fast self-recovery breakdown between anode electrode and body. Nickel (Ni) coating on anode electrode was tested to suppress the breakdown. It was found at least not bad to insulation and vacuum of the klystron. Although further studies, more statistics and longer running periods may be necessary, such coating is expected to suppress the momentary electrical breakdown in the tube.

Introduction

Several of 55 klystrons (E3786) made by Toshiba Corp. did not work well because of amplitude modulation (AM). This phenomenon is caused by momentary electrical breakdown between the anode electrode which is at the negative high voltage and the body at the earth level. In the moment of breakdown the anode potential gets near to that of the body. Then the beam current in the klystron is increased and the output power is increased momentarily. It is due to electrical breakdown along the insulation ceramic between anode and body$^{1)}$. Inner wall of the ceramic is very often contaminated with copper compounds as shown in Fig. 1. We suspect such copper compounds came from the anode electrode by sputtering in the moment of electrical breakdown or by glow discharging in vacuum.

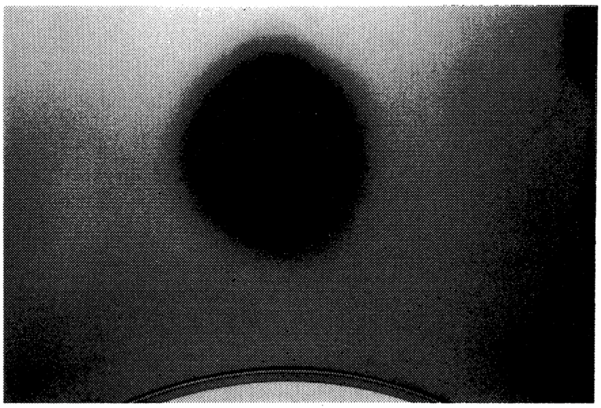


Fig. 1 Contamination of the Anode Ceramic.

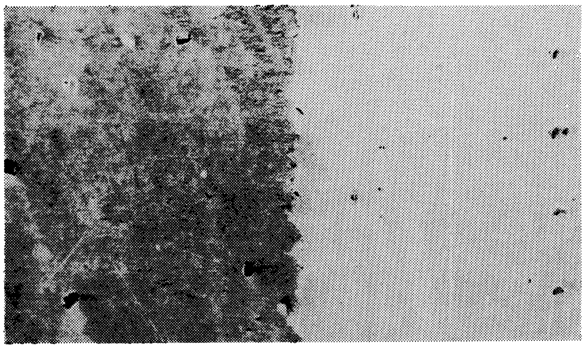
In order to suppress these phenomena two countermeasures were taken. One is reinforcing the shielding ring on the body to relax the local electric field at the brazed interface. The other is making grooves inside the ceramic to enlarge the breakdown path and ensure the non contaminated zones on the ceramic surface. Two klystrons taking these countermeasures, however, still have shown the same phenomena.

We then tried to coat the outer side of the anode electrode with a material that is harder to be sputtered than copper. So we searched what material is the best. The required characteristics are as follows . One is smll sputtering yield. A second is hardness of discharging. A third is easiness of coating on the anode electrode made of copper. And the fourth is usability in high vacuum.

Nickel, chromium oxide and titanium nitride were selected as candidates which fulfill these conditions$^{1)}$. Because coating process is easier than others, nickel was tried first. In order to check the availability of coating, a test bench was made to test the insulation of small ball bap. The result was fed back to the tube producton line and the anode electrode of one real klystron was coated with nickel. Balls coverd with barium (Ba) layer on both sides were also examined in the same test bench. These resuts are summerized as follows.

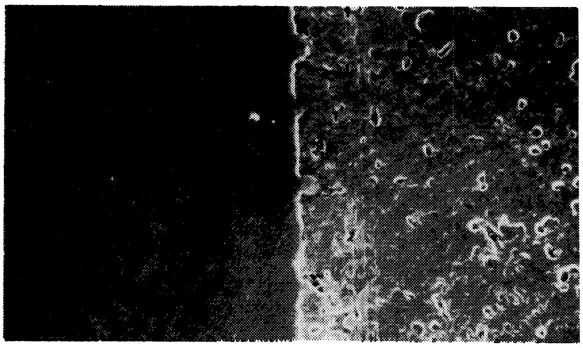
Surface of Ni coating

Ni coating was done on copper by electrical plating in Toshiba Corp. Copper ball is made of the same material and finished the same way as the anode electrode. Thickness of the Ni layer is 1.0-1.5µm. As theklystron experiences several heat cycles during the brazing process, Ni diffuses into copper to mak cupronickel. Fig. 2 is a SEM photo



× 100 (by SEM) Cu ← → Ni Coating

Fig. 2 Surface of the Ni Coating without Heating.



× 100 (by SEM) Cu ← → Ni Coating

Fig. 3 Surface of the Ni Coating after Heating.

of the surface of copper with and without Ni without heat process. Fig. 3 shows SEM photo of the Ni surface after two-fold heat cycles (1000 °C, 35 minutes for Au/Cu brazing and 850 °C, 30 minutes for Ag/Cu brazing). Both figures show that the surface of Ni after heating is rougher than copper. The Ni coated ball after heating really looks and feels like pear-skin. But an anode electrode coated with Ni looks more like copper probably due to small differences of conditions during heat process. The anode electrode is shown in Fig. 4 (before heating) and in Fig. 5 (after heating).

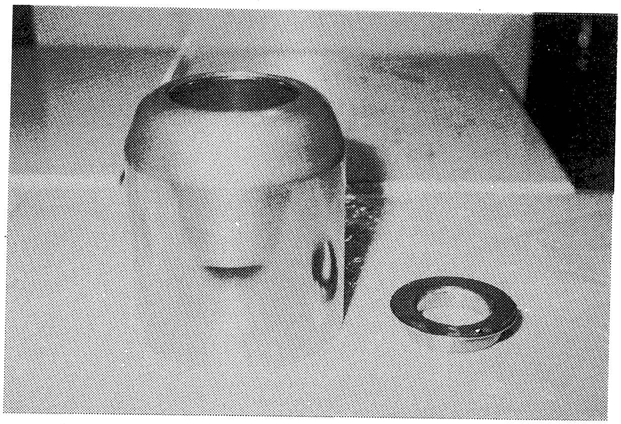


Fig. 4 Klystron Anode coated with Ni before Heating. Upper Side of the Border Line is Ni Coating.

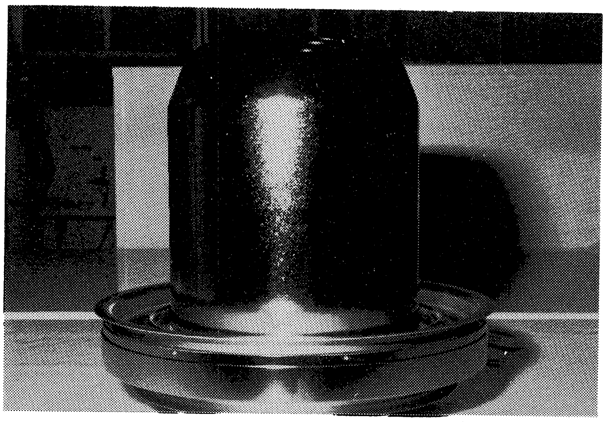


Fig. 5 Klystron Anode coated with Ni after Heating.

Insulation test on ball gaps

Before electroplating a real anode electrode we tested the insulation of a copper ball coated with Ni. Then we compared a it with that of a pure copper ball. The material is OFHC (Hitachi class 1) copper and the surface finish is 1S. After being machined, the balls were degreased, dipped in an acid and rinsed in pure water. Schematic diagram of the ball gap test setup is showen in Fig. 6. Diameter of the ball is 1 3/16 inches. Because the nearest part of the body of klystron to the anode is made of stainless steel, the opposite ball electrodes is made of stainless steel (SUS304, ball for a bearing is used). It is grounded to the earth, while minus high voltage is applied to the ball under test. The vacuum level is kept below 5×10^{-9} torr.

According to the test, Ni coated copper and pure copper discharged at 20 kV and 25kV for the gap of 0.2mm respectively. The electrical field strength at that time were 1MV/cm and 1.25MV/cm, respectively. The difference is so samll and the resilt of this test is even satisfactory. Then we adopted this coating procedure to a real tube (S/N T47A). Part of the anode electrode surface was electroplated with Ni just the same way as the copper ball. The result is as follows.

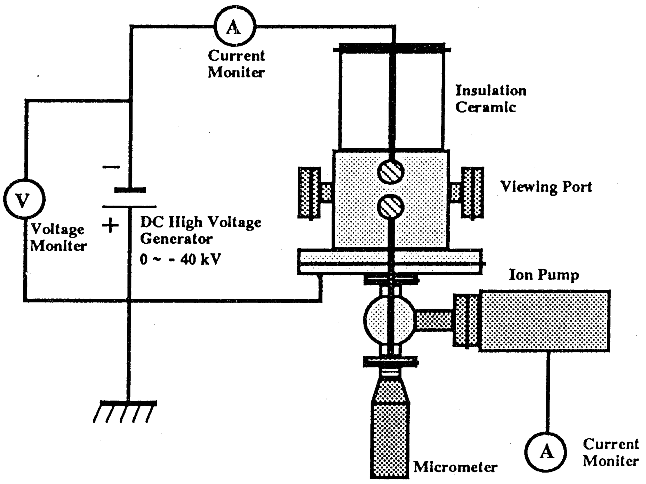


Fig. 6 Schematic Diagram of the Setup of Ball Gap Test.

Spot knocking (SK) test of a real klystron

SK is a conditioning process to recover the insulation between anode and body or between anode and cathode. SK was done for klystron (S/N T47A). At first, a small negative voltage was applied to anode and then voltage was increased gradually. At a certain voltage level, discharge occurs with a gas burst. After that, the insulation usually becomes better than before. After repeating many discharges, 90kV was finally reached and could be kept applying stably between anode and body.

Most Toshiba klystrons (E3786) show the leak current of about 0.05mA between anode and body when 90kV is applied after SK. In case of T47A, however, the leak current was about twice as much as it. But the insulation was still sufficiently good, the gas burst was not frequent and SK time was even shorter than other klystrons.

Insulation test on ball gaps covered with Ba

Anode and body electrodes of klystrons are usually covered with Ba layer evaporated from cathode. If the surface of copper is covered with Ba, as the work function of Ba is smaller than that of copper, the field emission becomes larger 2). Therefore the breakdown voltage between anode and body may be changed.

So, as the second step we tested the insulation of between balls coated with Ba. Coating was done by vacuum evaporation in which a cathode button was used as a Ba source. Test balls and test conditions are the same as before. This time a small leak current was monitored with a high resolution nano-ammeter which was placed on a high voltage stage. Fowler-Nordheim (F-N) plots3) were taken on Ni(Ba) vs SUS(Ba) balls and Cu(Ba) vs SUS(Ba) balls after each discharge. These plots are summarized in Fig. 7 and Fig. 8, respectively.

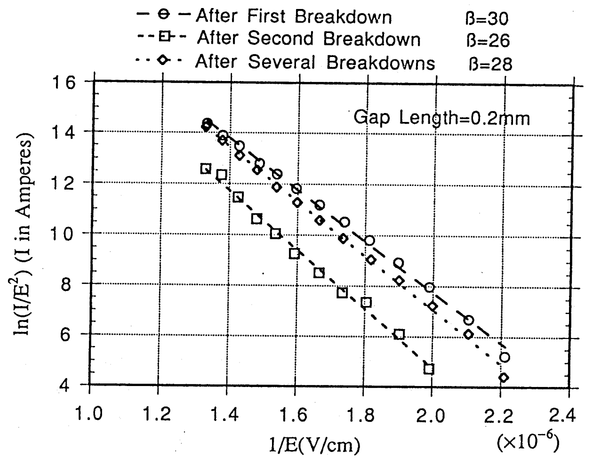


Fig. 7 F-N Plot of Ni(Ba) vs SUS(Ba).

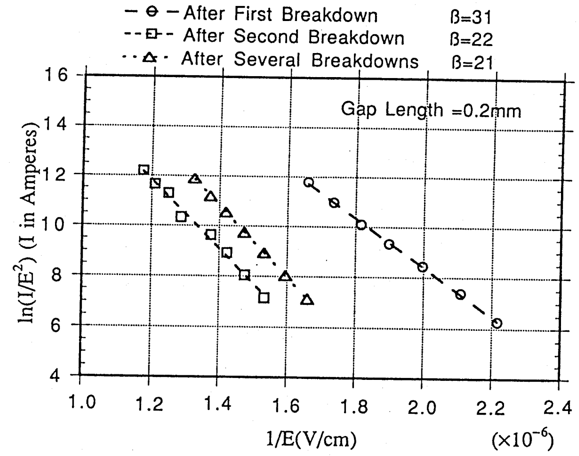


Fig. 8 F-N Plot of Cu(Ba) vs SUS(Ba).

From gradients of these F-N plots we can calculate the field enhancement factor, ß, assuming that the work function of the surface is that of Ba. The values of workfunction of Ni, Cu and Ba are 5.25, 4.51 and 2.66eV, respectively. After several discharges, ß of the Ni(Ba) and Cu(Ba) balls set became 28 and 21, respectively. The leak current of the Ni case was about ten times larger than that of the Cu case for the same voltage. The breakdown voltages in both cases were the same, 20kV.

Conclusion

Ni coating on the copper electrode showed no deterioration and no bad effects on the insulation between electrodes or vacuum in the tube. Ni and cupronickel have higher melting points than pure copper. So the sputtering of copper on to the ceramic will be suppressed. Forming of undesirable semiconducting phase of Cu_2O may be blocked owing to the coexistance of Ni. Focusing conditions will not be modified by the ferromagnetism of Ni, because the layer is so thin and Ni forms cupronickel whose Curie point is low. It is expected that this Ni coating is highly effective to suppress the fast self- recovery breakdown which induces pulse AM in the klystron output and interrupts the operation of TRISTAN so often. Furter investigations will be continued on the behavior of this modified version (S/N T47A) of the klystron, E3786.

Acknowledgement

We would like to thank Mr. Y. Takeuchi for his advice and Messrs. Y. Kawakami, M. Tamanaha and Y. Imaizumi of Toshiba Corp. for their collabrations, helps and sample preparations.

References

1) S. Isagawa et al., "Result Status of High Power CW Klystrons Developed for TRISTAN", Proc. 14th Int. Conf. on High Energy Accelerators, Tukuba, Aug. 1989, Part. Accel. 29, pp 793-800, Apr. 1990, KEK Preprint 89-107, Sep. 1989.
S. Isagawa and M. Yoshida, "Insulation Tests of the Anode Ceramic for a Toshiba Klystron E3786, T36, which showed Negative Spikes in Anode Current", Internal Report at KEK, Dec. 1988.
2) R. H. Good et al, "Handbuch der Physik", pp 183-188, 1956
3) R. V. Latham, "High Voltage Vacuum Insulation", pp 51-55, Academic Press, 1981.