IMPROVEMENT OF Cu-Cr ELECTRODE SURFACE UNDER IMPULSE VOLTAGE CONDITIONING IN VACUUM

Hiroki Kojima, Hideaki Yasukawa*, Ryouki Nishimura*,
Hiromasa Sato+, Hitoshi Saito+, Yasushi Noda+, Hitoshi Okubo*

EcoTopia Science Institute, Nagoya University, Nagoya, Japan
*Department of Electrical Engineering and Computer Science, Nagoya University, Nagoya, Japan
+ Japan AE Power Systems Corporation, Hitachi, Japan
Email: h-kojima@esi.nagoya-u.ac.jp

Abstract: As vacuum attracts attention from a viewpoint of high insulation performance and environmental-friendliness, vacuum circuit breakers (VCBs) are expected to develop into higher voltage level. In this paper, we discuss the relations between the surface state and the conditioning mechanism of Cu-Cr electrode during impulse voltage application process in vacuum. The experimental results showed that the deposited layer at the cathode surface is formed by the anode material due to the impulse voltage application process. We finally concluded that under impulse voltage application process, characteristics of the cathode surface are changing to those of the anode material, and anode material could determine the final states of conditioning process.

1. INTRODUCTION

The insulation performance improvement is needed to develop high voltage VCBs and VI [1]. The spark conditioning technique is used to achieve a higher voltage. However, relations between electrode surface state and the conditioning mechanism are still not clear.

In this paper, we focused on the change of electrode surface state in the conditioning process by using Cu-Cr electrode and discussed the mechanisms of conditioning process in vacuum.

2. RESULTS AND DISCUSSION

We carried out the impulse voltage conditioning under quasi-uniform electric field for parallel plane electrode systems with Cu-50wt%Cr and/or SUS304 electrodes.

Figure 1 shows the saturated 50% BD voltages in 4 kinds of electrode material combination. The saturated BD voltages of electrode systems with SUS304 anode are higher than those with Cu-Cr anode. We can see in this figure that their final saturated voltages highly depend on the anode material.

Figure 2 shows the result of the Cu-Cr cathode surface observation in cathode:Cu-Cr/anode:SUS304 electrode system by EDX that was examined to a depth of 10 μm from the surface after the impulse conditioning. Fe, Ni and Cr which are major materials of SUS304 were detected at the cathode made by Cu-Cr. Similarly, in cathode : SUS304/anode : Cu-Cr electrode system, the material components of Cu-Cr anode were detected on the surfaces of SUS304 cathode. These results mean that after the impulse conditioning the cathode surface was covered by the deposition of anode materials, and the deposition formed the deposited layer of 10μm or more. Therefore, it is considered that during conditioning process, the material characteristic of cathode surface changes into that of anode surface.

In addition, in electrode systems with Cu-Cr cathode, because surface of the Cu-Cr electrode has rough, conditioning at the edge of Cu-Cr cathode takes many voltage applications. Therefore, we clarified that, in the early stage of conditioning process, many BD discharge spots concentrate at the edge of electrode.

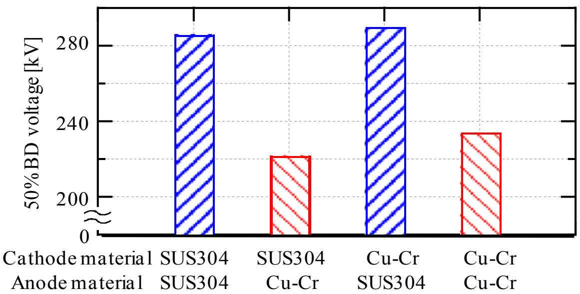

Figure 1 : Saturated 50% BD voltages in different combination of electrode material.

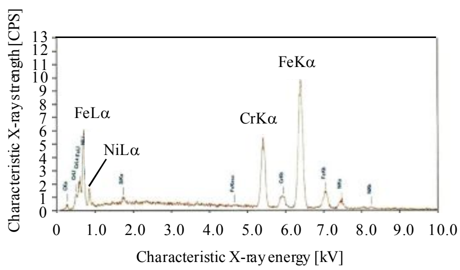

Figure 2 : EDX analysis after conditioning of the Cu-Cr cathode surface of Cu-Cr/SUS304 electrode system.

3. CONCLUSION

After impulse conditioning process, the cathode surface is covered with thickness of 10μm or more by the anode material. Therefore, characteristics of cathode surface change into those of anode material due to deposited layer during conditioning process.

In the early stage of conditioning process, initial surface state of cathode dominates BD discharge spot. On the other hand, after saturation of conditioning process, the characteristics of anode material can determine the final saturated BD voltage.

4. REFERENCES

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Hiroki Kojima
EcoTopia Science Institute
Nagoya University
Nagoya, Japan
Email: h-kojima@esi.nagoya-u.ac.jp

Hideaki Yasukawa, Ryouki Nishimura, Hitoshi Okubo
Department of Electrical Engineering and Computer Science
Nagoya University
Nagoya, Japan

Hiromasa Sato, Hitoshi Saito, Yasushi Noda
Japan AE Power Systems Corporation
Hitachi, Japan

***Abstract*— As vacuum attracts attention from a viewpoint of high insulation performance and environmental-friendliness, vacuum circuit breakers (VCBs) are expected to develop into higher voltage level. In this paper, we discuss the relations between the surface state and the conditioning mechanism of Cu-Cr electrode during impulse voltage application process in vacuum. The experimental results showed that the deposited layer at the cathode surface was formed by the anode material due to the impulse voltage application process. We finally clarified and concluded that under impulse voltage application process, characteristics of the cathode surface are changing to those of the anode material, and anode material could determine the final states of conditioning process.**

I. INTRODUCTION

The insulation performance improvement is needed to develop high voltage VCBs and vacuum interrupters (VI) in 120~168kV level [1, 2]. Therefore electrode systems are conditioned to get a reliable high electric strength. The spark conditioning technique is used to achieve a higher voltage [3], and the clarification of the conditioning characteristic is requested.

In general, electrode conditioning has been known as the method of improving weak area by melting electrode surface [4, 5], removing adsorption gas of electrode that would cause pre-breakdown current [6, 7]. In addition, it was found that the fine dispersion layer could be formed on the electrode surface, and improved the material characteristics being enhancement of the BD voltage [8-10]. However, relations between electrode surface state and the conditioning mechanism are still not clear. Therefore, in this paper we investigated the details about the relations between them.

We applied negative standard lightning impulse (LI) voltage under quasi-uniform electric field. We focused on the change of Cu-Cr electrode surface state with the conditioning process and discussed the mechanisms of conditioning process in vacuum.

II. EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 shows the experimental set up and the electrode configuration. We used the parallel plane electrodes with the gap length d=5 mm, under quasi-uniform electric field. The negative standard lightning impulse voltage (1.2/50 μs) was applied to the upper electrode. Cu-50wt%Cr or SUS304 electrode with diameter ϕ=22 mm was used for cathode and anode. 4 kinds of electrode material combination used in the experiments were shown in Table 1.

For voltage application procedure, we used up-down method from 24.6 kV with the voltage step ΔV = 4.1 kV. The illumination spots on the electrode surface at BD were observed by two digital cameras from two right-angled directions. The electrode surface was observed before and after conditioning process. In addition, after conditioning process, the electrode surface materials were analysed by energy dispersive X-ray spectrometry (EDX). During the conditioning process, the vacuum pressure in the chamber was kept at the order of 10^{-6} Pa.

Figure 2 shows the result of observing the electrode surface by microscope before conditioning process. In Fig. 2, the surface of the Cu-Cr electrode has rougher than that of the SUS304 electrode. It can be seen Cu and Cr areas exist separately in Cu-Cr electrode.

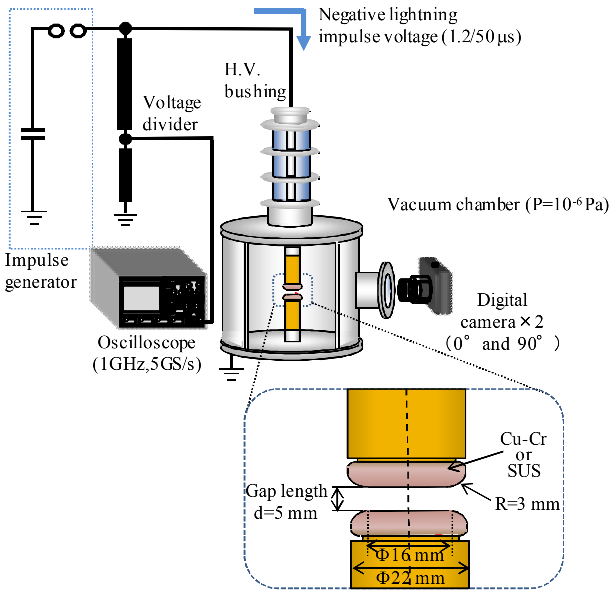
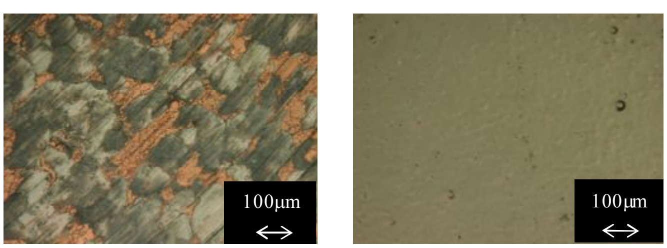


Fig. 1. Experimental setup and electrode configuration.

Table 1. Combination of ϕ22 mm electrode.

Electrode [mm]	Gap [mm]	Cathode material	Anode material
ϕ22	5	SUS304	SUS304
		Cu-50wt%Cr	Cu-50wt%Cr
		Cu-50wt%Cr	SUS304
		SUS304	Cu-50wt%Cr



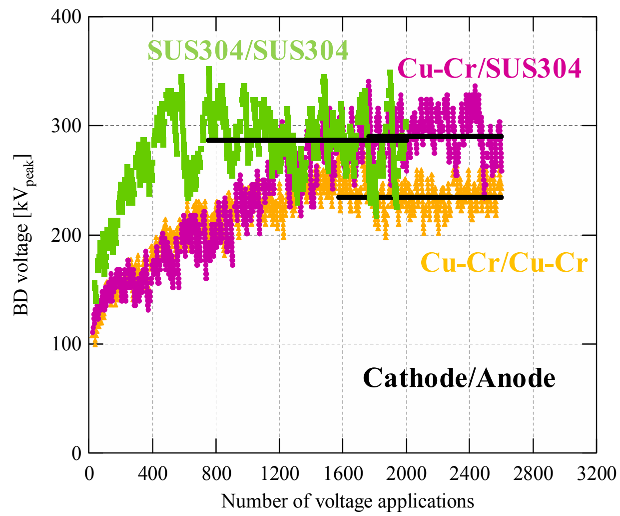
(a) Cu-50wt%Cr, R_a= 1.39μm. (b) SUS304, R_a= 0.60μm.

Fig. 2. Electrode surface before conditioning process.

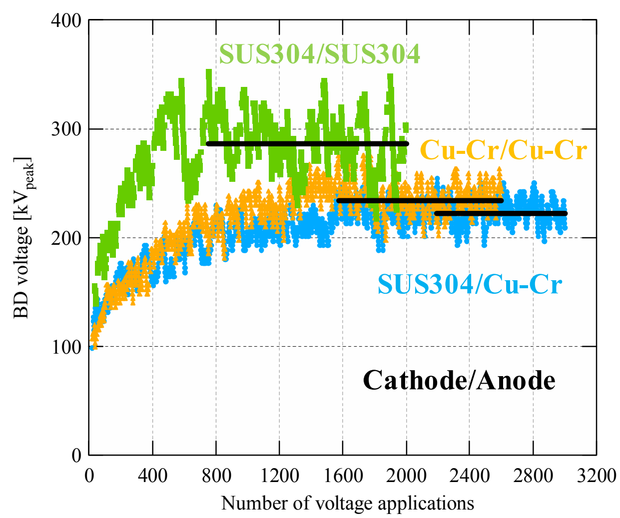
III. MESUREMENT AND DISCUSSION

A. Conditioning history and analysis of electrode surface by SEM and EDX.

Figure 3 shows the electrode conditioning histories by up-down method. BD voltages of the all electrode systems were enhanced by a lot of impulse voltage applications, reaching saturation. The saturated BD voltages of electrode systems with SUS304 anode are higher than those with Cu-Cr anode. In Fig. 3 (a), the BD voltage history of Cu-Cr/SUS304 electrode system is similar to that of Cu-Cr/Cu-Cr until 1100 times of voltage application. Afterwards, the BD voltage approaches to that of SUS304/SUS304. In Fig. 3 (b), the BD voltage history of SUS304/Cu-Cr depends on Cu-Cr used as the anode material from early stage of the conditioning process. Figure 4 shows the saturated 50% BD voltages in 4 kinds of electrode material combination. We can see in this figure that their final saturated voltages are highly depended on the anode material.



(a) Feature of BD voltage history of Cu-Cr / SUS304.



(b) Feature of BD voltage history of SUS304 /Cu-Cr.

Fig. 3. BD voltage history by up-down method for different electrode materials.

Figure 5 shows the result of the cathode surface observation by SEM after the impulse conditioning process in SUS304/Cu-Cr. In Fig. 5, the surface was melted by impulse conditioning process and many melted particles can be seen on the cathode surface. The similar situation was also found on the cathode surface in electrode system with SUS304 anode.

Figure 6 shows the results of material analysis by EDX that were examined to a depth of 10 μm from the surface after the conditioning process. In Fig. 6 (a), Fe, Ni and Cr which are major materials of SUS304 were detected at the cathode made by Cu-Cr. On the other hand, in Fig. 6 (b) at the anode, only anode material is detected and cathode material (Cu-Cr) is not detected. Similarly, in Figs. 6 (c) and (d), the material components of anode were detected on the both surfaces of anode and cathode. These results mean that after the impulse conditioning process the cathode surface was covered by the deposition of anode materials and the deposition formed the deposited layer of 10μm or more. Therefore, it is considered that during conditioning process, the material characteristic of cathode surface changes into that of anode surface and the anode material strongly influences the saturated BD voltage as shown in Fig. 4.

In addition, we has found in a past research that by the impulse conditioning process the fine dispersion layer was formed at the surface of the electrode and that the fine dispersion layer could enhance the withstand voltage [8]. From this fact, we can suppose that the fine dispersion layer correspond to the deposited layer obtained in this paper.

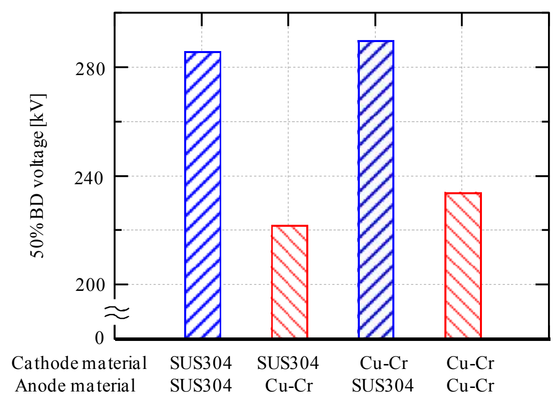


Fig. 4. Saturated 50% BD voltages in different combination of electrode material.

B. *Transition characteristics of BD discharge spot area during the conditioning process*

It can be thought that the cause of BD is electron field emission from the cathode. However, from the above-mentioned results, we clarified that the cathode surface state changed greatly by conditioning process. From this view point, the transition of BD discharge spot area of the conditioning process was examined.

We define the area within 7.9 mm from the center of the plane electrode, where the electric field is lower than 90% of maximum electric field, as "Central area" of the electrode. Other area is defined as "Edge area" of the electrode.

Figure 7 shows the transition of BD discharge spot area ratio in the electrode "Central area" every 200 voltage applications. The conditioning process of electrode surface occurs from "Edge area", because "Edge area" has higher electric field than "Central area". From Fig. 7, it seems that the transition of BD discharge spot area ratio is determined by cathode material. In the electrode systems with SUS304 cathode, BD occurred at the whole of electrode surface during conditioning process. By contrast, BD discharge spot area in the electrode

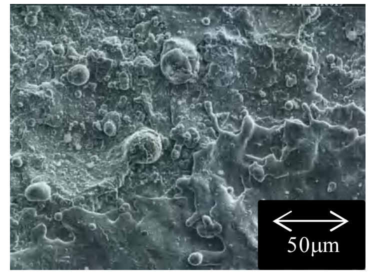
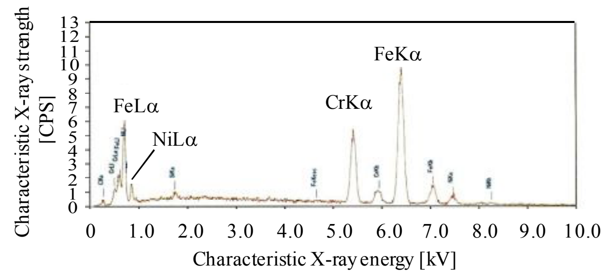
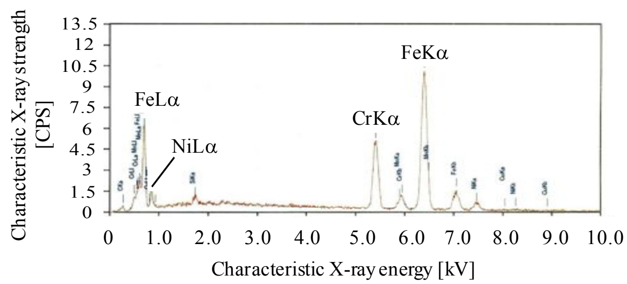


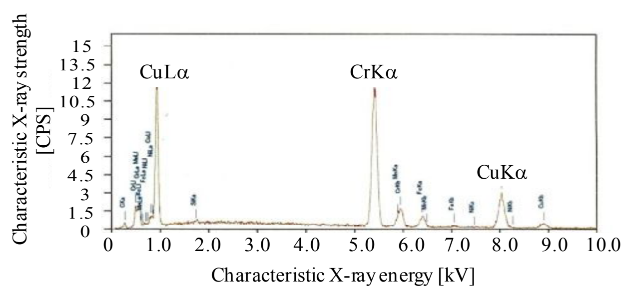
Fig. 5. SEM analysis of the cathode surface after conditioning process in SUS304/Cu-Cr.



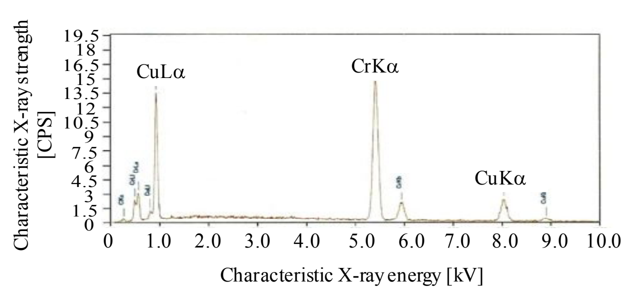
(a) Cu-Cr : Cathode of Cu-Cr/SUS304.



(b) SUS304 : Anode of Cu-Cr/SUS304.



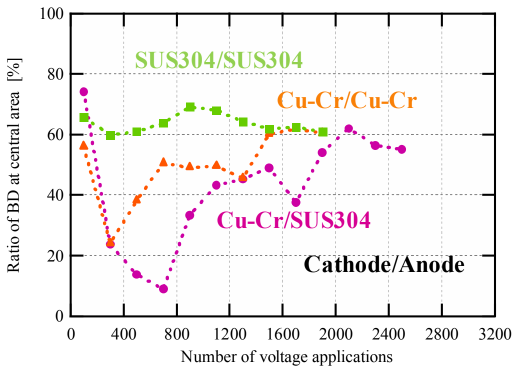
(c) SUS304 : Cathode of SUS304/Cu-Cr.



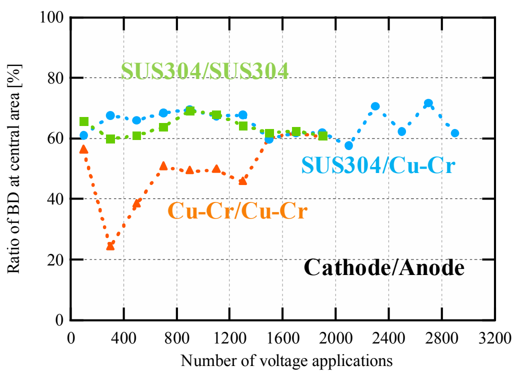
(d) Cu-Cr : Anode of SUS304/Cu-Cr.

Fig. 6. EDX analysis after conditioning of different electrode material systems.

systems with Cu-Cr cathode gradually shifted to the whole of electrode surface after BD concentrated on the edge. When BD concentrated on the edge, the deposited layer did not exist on the cathode surface in view of BD voltage history yet. As shown in Fig. 2, because Cu-Cr electrode has rougher surface than SUS304 electrode, it is considered that conditioning at the edge of Cu-Cr cathode takes a lot of impulse voltage applications. Figure 8 shows the minimum ratio of BD at "Central area" during conditioning process. In Fig. 8, in the case of Cu-Cr cathode, because the edge of Cu-Cr cathode takes a lot of impulse voltage applications more than that of SUS304 cathode, the minimum ratio of BD at "Central area" is lower.



(a) Feature of transition of BD discharge spot area in Cu-Cr/SUS304.



(b) Feature of transition of BD discharge spot area in SUS304/Cu-Cr.

Fig. 7. Ratio of BD at "Central area" for different electrode materials during conditioning process.

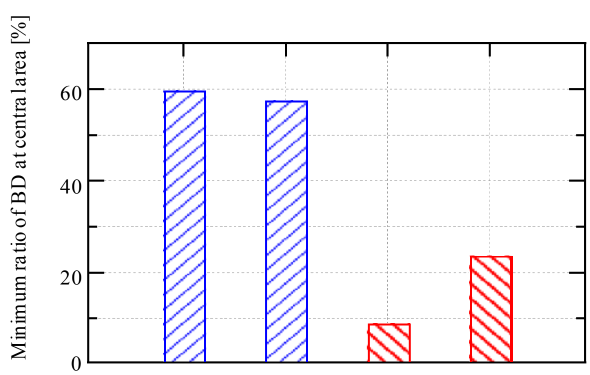


Fig. 8. Comparing the minimum ratio of BD at "Central area" in different combination of electrode material.

From Figs. 4 and 8, we clarified that the cathode material dominates BD discharge spot at the early stage of conditioning process and anode material can determine the final saturated BD voltage.

IV. CONCLUSIONS

In this paper, we investigated the Cu-Cr electrode surface state and the BD conditioning mechanism under quasi-uniform electric field in vacuum. As a result, we found the following characteristics of conditioning.

1. After impulse conditioning process, the cathode surface is covered with thickness of 10μm or more by the anode material. Therefore, characteristics of cathode surface change into those of anode material due to the deposited layer during conditioning process.
2. In electrode systems with Cu-Cr cathode, because surface of the Cu-Cr electrode has rough, conditioning at the edge of Cu-Cr cathode takes a lot of impulse voltage applications. Therefore, in the early stage of conditioning process, many BD discharge spots concentrate at the edge of electrode.
3. In the early stage of conditioning process, initial surface state of cathode dominates BD discharge spot. On the other hand, after saturation of conditioning process, the characteristics of anode material can determine the final saturated BD voltage.

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