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Developing anti-metallic contamination polyester membranes with nuclear pore technique

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Abstract Surface contamination by conducting materials, metals in particular, is one of the important causes for electric breakdown of insulators under high voltage. In order to explore the feasibility of nuclear track modification for anti-metallic contamination, polyester membranes with different thickness were bombarded by ^{32}S ions from the HI-13 tandem accelerator of CIAE. The tracks formed on the surface of the membranes were etched under different conditions. The insulating capability of the treated membranes was evaluated by using silver coatings to simulate the surface metallic contamination. The results indicated insulators with the surface modified by nuclear pore technique have an improved capability of anti-contamination of metals. The sample with 144 nm Ag coating is not breakdown under 1000 V.

Key words Nuclear Tracks, High voltage, Anti-metallic contamination

1 Introduction

In high voltage technique, breakdown of insulators may occur due to surface contamination of conducting materials, such as metal vapor evaporated by sparking. A conventional solution to this kind of problems is to make an insulator with undulating surface, so as to increase conducting distance of the insulator. However, an insulator surface can be enlarged to limited extent, and the performance of against contamination is not satisfactory. Fischer *et al*.[1] treated mica with nuclear track technique to increase the surface porosity from 70% to 220%, and the anti-metallic contamination performance was greatly improved.

In this work, polyester membranes were bombarded with 80 MeV ^{32}S ions. The latent tracks were etched into pores of conical shape. The etching process continued until the adjacent conical pores in membrane surface were almost overlapped (parted in several nanometers). The membranes, with pores of about 10 μm in length, were coated with silver to check the of anti-contamination performance, and the membranes with thick silver coating (144 nm, or 128 $\mu g/cm^2$) performed satisfactorily, without any surface current at 1000 V.

2 Experimental

^{32}S ion beams at 80 MeV from the HI-13 tandem accelerator[2] at CIAE were used to bombard the polyester membranes for nuclear pore formation. From a parameter calculation with SRIM2000[2] (Table 1) for ^{32}S ions in polyester, the depth of latent tracks in polyester is a little over 27 μm, so the polyester membrane used in this work was 50 μm thick. The ion dose was $10^8/cm^2$.

Table 1 Parameters for interaction of S ions with polyester[3]

Ion Energy /MeV	Electric dE/dx. / MeV·cm^2·mg^{-1}	Nuclear dE/dx /MeV·cm^2·mg^{-1}	Projected range /μm	Longitudinal straggling /μm	Lateral straggling /μm
80.00	19.49	0.01737	27.22	0.8639	0.3840

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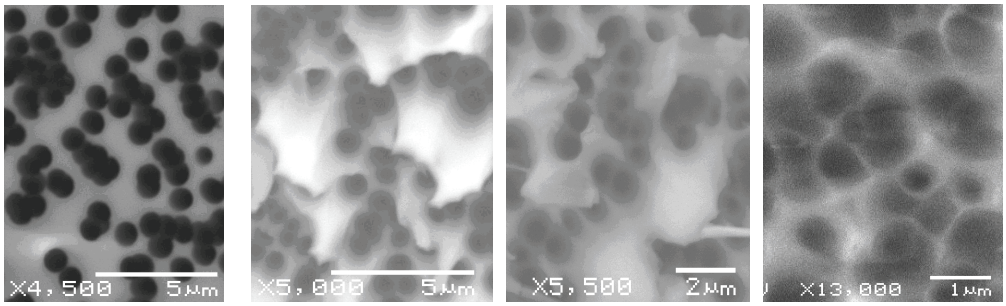
Because of energy deposition in the polyester membranes by the ^{32}S ions, the chemical bonds were broken and latent tracks were formed [3–9]. The bombarded polyester samples were etched by sodium hydroxide. The nuclear pore size and shape depend on the etching temperature, time and NaOH concentration [10–20].

A DMX-220A evaporator was used to coat Ag and Ti films of different thicknesses on the treated polyester membrane to simulate surface metal contamination for insulation test. The membrane samples were placed at 25 cm from the tungsten oven. The pressure was 0.4 Pa, and the deposition rate was about 0.1 μg·cm^{-2}·s^{-1}. Untreated polyester membranes were coated by silver (75 μg/cm^2) as the control. As one of the best conductors, silver is effective to evaluate the membranes' performance of anti-metal contamination.

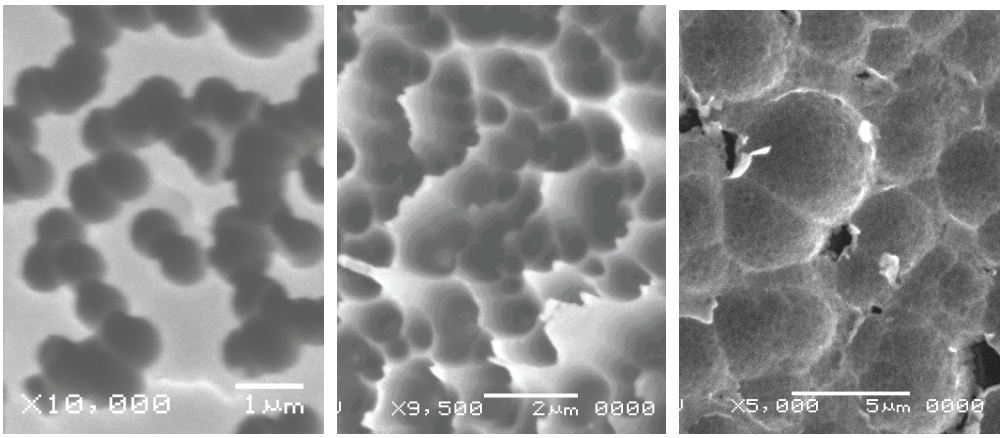
3 Results and discussion

Fig.1 shows SEM images of conical nuclear pores in the membranes etched for different minutes in NaOH solution of 6.0 mol/L at 65°C. The diameter of nuclear pores increased with the etching time, while the distance between pores decreased in 42 min, when the distance between pores began to increase, as the bulk etching peeled off sufficient thickness of the membrane, hence the shallower pores. The optimal aspect ratio of the pores was formed at about 42 min of etching time under our experiment conditions.



a) 18 min b) 27 min c) 42 min d) 90 min

Fig.1 Nuclear pores of different sizes in polyester membranes etched for 18–90 min in 6.0 mol/L NaOH at 65°C.



a) 18 min b) 42 min c) 90 min

Fig.2 Nuclear pores in polyester membranes etched in different minutes and coated with Ag of 128 μg/cm^2.

Fig.2 shows nuclear pores in the membranes coated with Ag of 128 μg/cm^2. One sees that very little Ag grains deposited on surface of the sample etched for 18 min (Fig.2a) entered into the nuclear pores, as the size of nuclear pores is much smaller than the pore distances. With lengthened etching time, the Ag grains

began to go into the nuclear pores, which became honeycombed and almost overlapped with each other (Fig.2b), with the pore diameter ranging from 1 μm to 1.8 μm, and the distance between two pores from 100 nm to 200 nm. In Fig. 2(c), the 90-min etching peeled off substantial layer of the surface, the pores became shallower, and the Ag grains covered the entire surface of membrane.

Six samples were measured with an ohmmeter (9 V) and a Glassman high voltage supply at 1000 V and 1500 V (see Fig.3 for a schematic diagram of the current measurement). Samlpe 1 is the control (non-bombarded). Sample 2–5 had been bombarded to 10^8/cm^2 by 80 MeV ^{32}S ions. Sample 2 was coated with 60-nm silver without etching. Sample 3 had no treatment after bombardment. Sample 4 was etched but not coated. Sample 5 and 6 were etched and coated with silver and titanium, respectively. In the measurement, two pinchcocks were nipped at two tips on the cross a 2 cm × 2 cm sample.

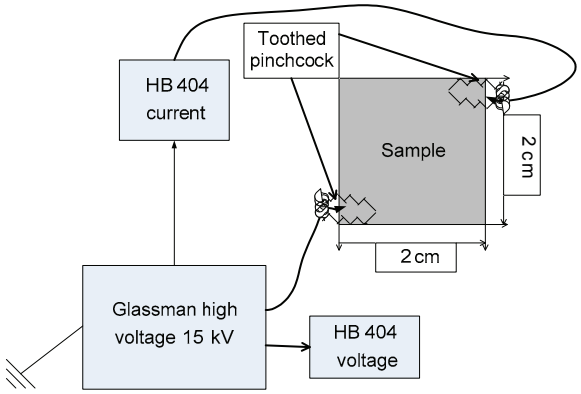


Fig. 3 Schematic diagram of the current measurement.

Table 2 Surface currents of the control and bombarded (10^8/cm^2) samples measured at different voltages.

Samples	Ag coating thickness / nm	Current/A		
		9 V	1000 V	1500 V
1. Un-bombarded		0	0	0
2. Bombarded and coated with silver	60	Breakdown	Breakdown	Breakdown
3. Bombarded		0	0	0
4. Bombarded and etched		0	0	0
5. Bombarded, etched, and coated with Ag	144	0	0	Breakdown
	200	0	Breakdown	Breakdown
	300	0	Breakdown	Breakdown
6. Bombarded, etched and coated with Ti	400	0	Breakdown	Breakdown
	500	0	Breakdown	Breakdown

Table 2 shows the test results. The currents are zero at 9 V for all samples except Sample 2 coated with silver of 75 μg/cm^2 (60 nm). Among all the samples, Sample 5, in which the nuclear pores were formed and coated with Ag of 128 μg/cm^2, is the only one that endued against 1000 V. The reason for its resistance to 1000 V lies mainly in the larger number of pores formed on the honeycombed surface, and this greatly increases the creepage distance of electrons.

Consequently, from the above experiments, the following facts were observed:

(1) Etching conditions are the key to produce desirable pores. Under the conditions used in this work, 42 min was found to be optimal etching time.

(2) Nuclear pores with high density, large pore size, and conical shape are favorable for stronger anti-metal contamination capability.

(3) Homogeneous distribution of nuclear pores is another sticking point for producing insulators with strong anti-metal contamination property.

(4) Insulators with the surface modified by nuclear pore techniques have improve capability of anti- contamination of metals. The sample with 144 nm Ag coating is not breakdown under 1000 V.

4 Conclusions

The polyester membrane with nuclear tracks has capability of anti-metal contamination if (1) the latent nuclear tracks on the polyester surface are as much as 10^8/cm^2; (2) the nuclear tracks are etched into honeycombed pores with NaOH solution (6.0 mol/L,

65°C); (3) the depth of contaminated metal such as Ag and Ti is lower than 144 nm; and (4) the high voltage is lower than 1000V.

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