RPC electrode material study

Changguo Lu[1]
Princeton University, Washington Road, Princeton, NJ 08544, USA

Abstract

Various aspects of RPC electrode material, such as surface smoothness, surface UV sensitivity and its resistance to HF attack, have been studied. Based on these studies we can direct our R&D effort to some of the most critical issues related to RPC performance and aging.

Keywords: RPC, Bakelite, electrode, HF, Linseed oil, UV sensitivity

1. Introduction

Due to the wide application of RPC technology the R&D on further understanding the basic building material — Bakelite electrode is urgently needed. The surface quality of Bakelite sheet has been progressively improved, a new type of Bakelite sheet that does not require Linseed oil coating has been successfully developed at IHEP, Beijing [1]. With this Bakelite sheet IHEP has produced more than 1300m^2 of RPC chambers and installed on BESIII detector.

As we know that the majority of RPCs, which were built by an Italian company General Technica, used Italian Bakelite sheet. They require the inner surfaces of the electrodes to be coated by 2-propanol (or similar chemical solution) diluted Linseed oil, otherwise its huge noise rate prohibits the chamber from any practical application. The IHEP's technique made a big step forward to avoid this labor intensive and usually troublesome oiling step.

In this paper we are going to report our study on several related issues, such as why the original non-oiling RPC is so noisy, what roll the Linseed oil plays, etc.

2. How the surface quality affects the RPC noise rate

We use an Atomic Force Microscope (AFM) to study the surface morphological structure of the Italian Bakelite sheet. A 3-D image is shown in Fig. 1.

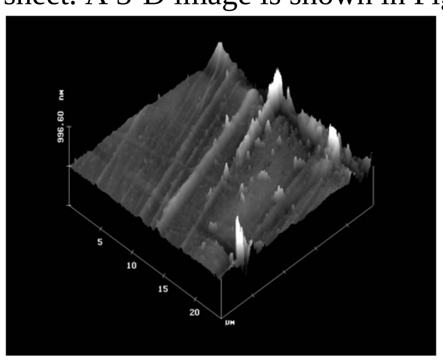


Figure 1. AFM image of the BaBar Bakelite surface morphological structure.

From Fig. 1 we can see that the feature structure of the surface defects could be categorized into four types shown in Fig. 2: "pin," "ball," "dome," and "ridge." We

[1] Tel.: 01-609-258-4421; fax: 01-609-258-6360; e-mail: changguo@princeton.edu.

have used finite element analysis software ANSYS to calculate the electric field variation due to these defects.

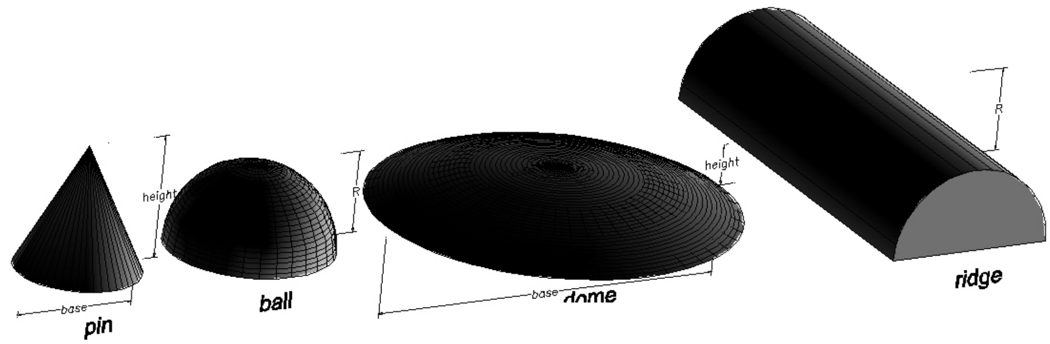
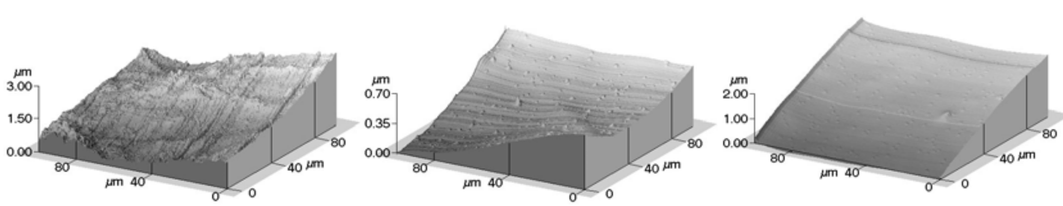


Figure 2. Illustration of the parameters of the surface defects used in the Finite Element Analysis calculation.

The FEA results listed in Table 1 show that the most serious defect type is the "pin". We also use AFM to look at the Linseed oil coated Italian Bakelite surface shown in Fig. 3. The bare surface shows rough structure, coated with thinned Linseed oil (B) the surface becomes smoother, coated with less thinned Linseed oil the surface becomes very smooth. Therefore we can definitely see the important roll of Linseed oil coating: it covers the surface morphological defect, makes the surface less sensitive to the field emission, a like source of high dark current and high singles rates.

Table 1. Maximum electric field at the defect, for V = 1000V in a 2mm gap (note: in a real RPC the voltage between two electrodes is usually 8000V, almost an order of magnitude higher than 1000V).

	"pin"				"ball"		"dome"	"ridge"	
Height(mm)	0.010	0.010	0.010	0.002	0.01	0.002	0.01	0.01	0.002
Base(mm)	0.004	0.010	0.020	0.002	0.02	0.004	0.06	0.02	0.004
E_{max} (MV/m)	23.6	8.58	5.75	3.25	1.49	0.976	0.871	0.999	0.976



(A) (B) (C)

Figure 3. Italian Bakelite surface morphology. (A) Bare surface; (B) Coated with 30/70 of Linseed oil/2-propanol; (C) Coated with 70/30 of Linseed oil/2-propanol.

3. Surface UV sensitivity

RPC is a parallel plate chamber. Between two electrodes the electric field is constant. The strong electric field presented on the surface would help to enhance the photoelectric efficiency. The UV photon created in every avalanche or streamer can hit the large surface of the cathode. To reduce the afterpulse/noise rate we would like to have the least UV sensitive material for the electrode. Therefore test the UV sensitivity of different materials and various surface treatment can give us some hints to this issue.

The test device, a McPherson VUV monochromator coupled with a 2-step avalanche chamber, is shown in Fig. 4. In this test the UV light splitter (5) and the PMT (6) are not used.

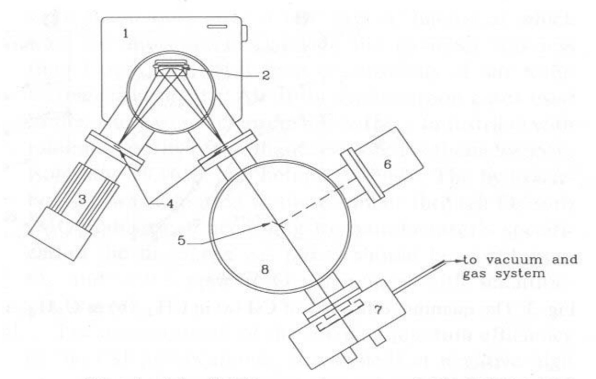


Figure 4. McPherson VUV monochromater used in UV sensitivity test for various RPC electrodes. (1) Model 234/302 0.2 m vacuum monochromator; (2) Halographic grating; (3) Model 632 deuterium lamp; (4) entrance and exit slits; (5) UV light splitter; (6) Model 654 side-on PMT with sodium salicylate screen; (7) 2-step avalanche chamber; (8) Vacuum compatible sample chamber.

The monochromatic light hits the front surface of the test sample, of which the back surface is coated with graphite paint that contacts the metal side of a G-10 plate and serves as the cathode of the 2-step avalanche chamber. The first part of the chamber, between the mesh electrode and the cathode, is a drift region, in which the E-field is rather low, the UV-photoelectrons from the cathode are drifting away from the cathode, but no gas avalanche. Very little photocurrent will be flowing through the test sample. The voltage drop across the test sample due to the photocurrent is completely negligible. Following the drift region, there is a second avalanche stage between the mesh and the anode. In this region the electric field strength is much higher than the drift region. Most of the drifting electrons would be crossing the mesh (90% of transparency), and entering this avalanche region. A Keithley electrometer is used to measure the total current flowing through this region. The monochromatic wavelength scans from 160nm to 220nm and the photocurrent response curve is recorded.

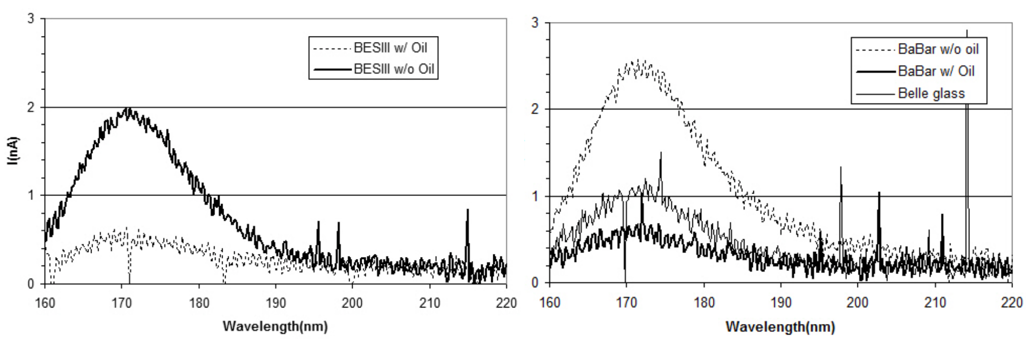


Figure5. VUV sensitivity test results, (A) IHEP BESIII samples, with and without Linseed oil coating; (B) BaBar bakelite samples with and without Linseed oil coating, and a Belle glass sample.

The test results are shown in Fig. 5. In the figure we compare the UV response of the surfaces with and without Linseed oil coating. It can be clearly seen that the Linseed oil coating dramatically cuts the surface UV sensitivity. The bare IHEP BESIII Bakelite surface has similar UV sensitivity as bare Italian Bakelite. We also tried various other oil coating on the surface, such as CVS baby oil and Breox oil[2], although these oil films are very thin, almost invisible, also they never can be dried, but their UV sensitivities are as low as Linseed oil coating. We tested another known drying oil, Tung oil[3]. The test results show that there is very small UV sensitivity reduction after coated with Tung oil.

4. HF production and adsorption/attack on the RPC electrode surface

4.1 HF production in RPC chamber

Hydrofluoric acid (HF) is produced in the RPC gas due to the decomposition of $C_2H_2F_4$, the main component of the most RPC gas mixtures in the gas avalanche/streamer. This very aggressive acid is believed to play a major role in damaging the RPC inner surface. This issue has been studied in detail by Santonico et. al [2]. The principle of the test is trapping the significant concentration of HF in the exhaust gas from RPC's by bubbling the gas through TISAB solution, where the fluorine is detectable as F- ions. A similar test device as mentioned in [4] is deployed in our lab. Figure 6 shows the amount of F^- ions trapped by the TISAB vs. time. At the same time the current drawn by the RPC chamber is also recorded.

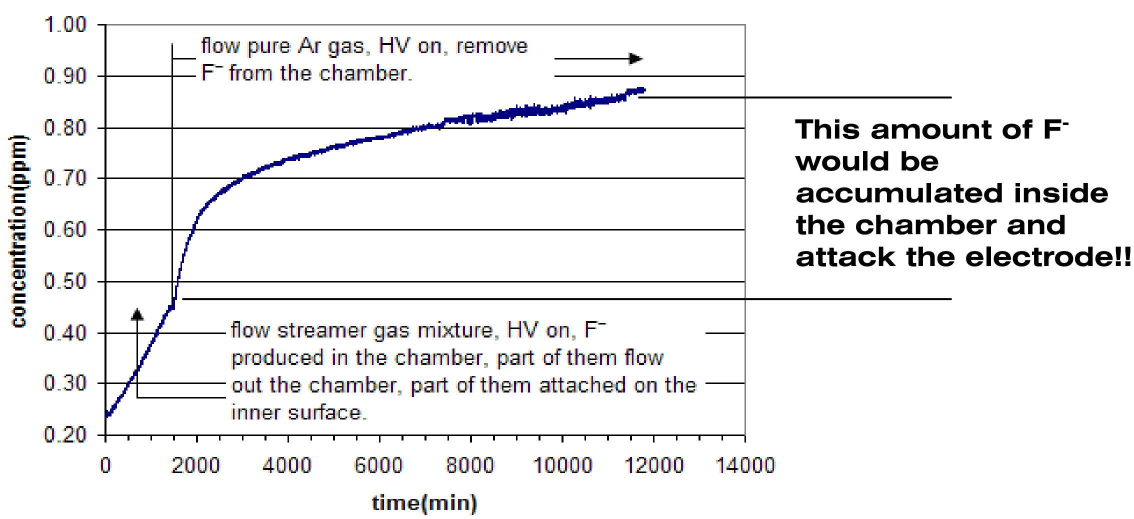


Figure 6. Accumulation of the fluoride ions in the TISAB sampling solution.

The first straight line section shows linear dependency of the fluoride concentration on the time. It indicates the steady production of fluoride in RPC gas discharges. This section corresponds to the un-adsorbed F^- production rate. The accumulating charge Q is calculated to be 22.5mC during the streamer operation, therefore the rate is about 1.19×10^{19} F^-/C. This result is more or less similar to R. Guida et al. data 1.3×10^{19} F^-/C [5], but only 40% of G. Aieli et al. data ~ 3×10^{19} F^-/C [4]. As we noticed that the gas mixture and RPC operation mode used in above two publications are different from us, so the difference of the F^- production rate is understandable.

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[2] Breox is a trade mark of BP Amoco and is used under license by Laporte Performance Chemicals UK Ltd.
[3] The other known drying oils are poppy seed oil, perilla oil and walnut oil.

The second section of the curve is recorded for the pure Ar gas operation. In pure Ar the UV photons created in the gas discharge can release the adsorbed fluoride from the surface, therefore we can see the fluoride concentration is increasing. Eventually it reaches saturation, from which we can estimate the total amount of fluoride produced. It is 0.45ppm F^- in 40CC solution after accumulating 22.5mC of charge. Therefore we derive the fluoride adsorption rate is $\sim 2.67\times10^{19}$ F^-/C. G. Aieli et al. reported that in their “pulsed operation” the F^- total adsorption rate is 3.6×10^{18} F^- /3mC [4]. It corresponds to 1.2×10^{21} F/C, which is 45 times larger than what we measured. Since they used different method, it is hard to make a reliable comparison.

4.2 Effect of HF on the resistive plate surface

HF is notoriously chemical reactive, it can attack many different materials. To get the sense of this corrosive action, we exposed various materials in the HF vapor environment. We measured their surface resistivity before and after the exposure.
By this we can quickly learn which electrode is more vulnerable to the HF attack. The test device is shown in figure 7.

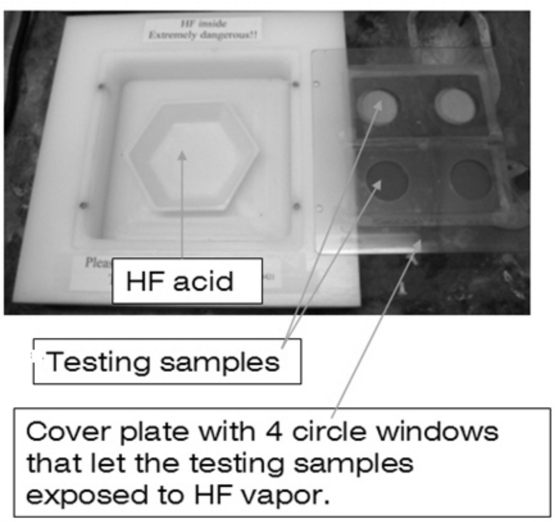

Figure 7. Test device to check HF attck sureface.

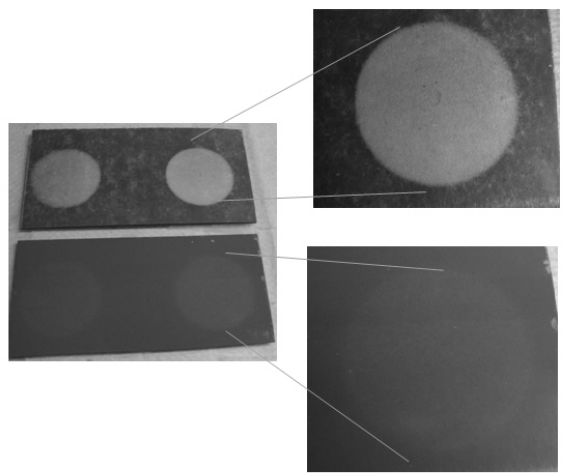

Figure 8. HF vapor corrosive action on BaBar Bakelite surface.

The BaBar Bakelite plate has two different surfaces, one side shows marble pattern, and the other side shows uniform brown color. The “marble” surface is smoother than brown surface, and used as inner surface. But its resistance to HF vapor corrosion looks worse according to our test results as shown in figure 8. After 24 hours of exposure to HF vapor the “marble” pattern has completely destroyed, also the surface looks very rough. The brown surface shows slightly discolored mark, much less severe than “marble” surface. Our test also shows that the Linseed oil coating on Bakelite surface can effectively protect the surface from HF vapor attack. After 24 hours of exposure there is no discolored area can be seen for the Linseed oil coated surfaces.

For BES III Bakelite its surface is badly attacked by HF vapor, see Fig. 9. The surface resistivity variation is shown in figure 10. In first hour of exposure the surface resistivity drops very fast.

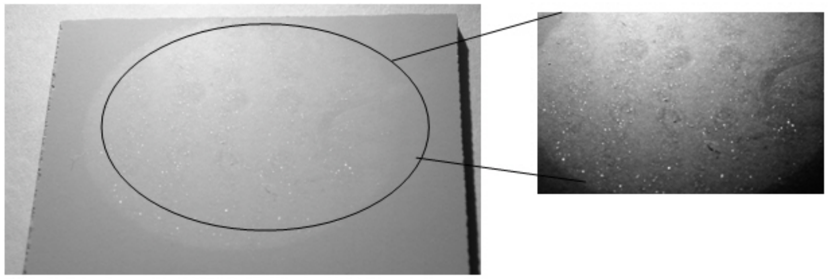

Figure 9. HF corrosive action on BES III bakelite surface.

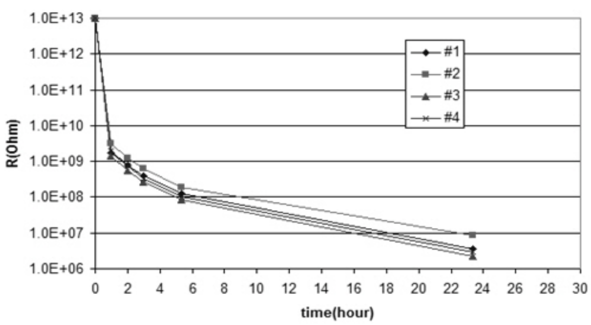

Figure 10. Surface resistivity variation of BESIII Bakelite sample upon the exposure to the HF vapor.

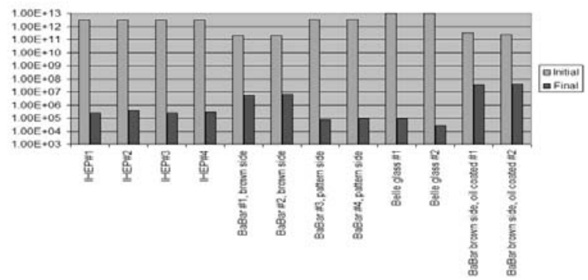

Figure 11. Surface resistivity change before and after exposed to HF vapor.

Belle's RPC glass surface, after exposed to HF vapor for ~24 hours, looks powdery fluffy, it was terribly damaged.

We summarize the HF corrosive effect on the surface resistivity for various RPC electrodes in figure 11. The Linseed oil coated BaBar bakelite is the most resistive to the HF vapor. In this regard the bare IHEP bakelite is not so robust.

What we observed in the working BaBar RPCs? The anode surface of an opened BaBar RPC shows many white spots, and on the opposite cathode surface the corresponding Linseed oil droplets can be seen (P. 33 of [3]). A possible explanation of these white spots is due to the HF corrosive effect, same as we observed in above test. Similar observation is reported in [5]. They found that the discolored areas show a higher fluorine concentration with respect to the reference surface.

Based on the above results we did the quantitative test for the damage of the electrode from HF due to operation of RPC chamber in following steps:

1) Pipette 90μL of 48% concentration HF acid into our test container, after the HF drop vaporized, it will produce ~ 1.3×10^{21} HF molecules inside the container. The total inner area of the container is 10^3 cm^2, $1.3\times10^{21}/10^3$ cm^2 = 1.3×10^{18}/cm^2, that is equivalent to a 2m^2 RPC operated at 5μA for 12.4 years assuming the previous derived HF adsorption rate = 2.67×10^{19} F^-/C.
2) Test the surface resistivity, the ratio of surface resistivity change (before/after) is ~500 to 900 for IHEP bakelite. The glass surface shows similar resistivity change.

Such a big surface resistivity reduction certainly will affect the normal RPC operation.

5. Conclusions

Two different Bakelite samples, one is made in Italy, the other is made in China, have been subjected to the studies reported in this paper.

- The surface morphological study with AFM shows various defects existing on the surface. Linseed oil coating can cover these defects effectively.
- Surface UV sensitivity for various Bakelite samples is studied with a VUV photospectrometer. The study reveals that the Linseed oil coating plays big roll in reducing the surface UV sensitivity.
- HF production, adsorption rate in RPC is also studied. The destructive action due to HF is studied quantitatively.

6. Acknowledgments

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Figure captions

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