

Study of glass properties as electrode for RPC

K. Raveendrababu^{a,c}, P. K. Behera^a, B. Satyanarayana^b and Jafar Sadiq^a

^a*Physics Department, Indian Institute of Technology Madras, Chennai 600036, India*

^b*Department of High Energy Physics, Tata Institute of Fundamental Research, Mumbai 400005, India*

^c*Physical Science Division, Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, India*

E-mail: prafulla.behera@gmail.com

ABSTRACT: Operation and performance of the Resistive Plate Chambers (RPCs) mostly depend on the quality and characteristics of the electrode materials. The India-based Neutrino Observatory collaboration has chosen glass RPCs as the active detector elements for its Iron Calorimeter detector and is going to deploy RPCs in an unprecedented scale. Therefore, it is imperative that we study the electrode material aspects in detail. We report here, systematic characterization studies on the glasses from two manufacturers. RPC detectors were built using these glasses and performances of the same were compared with their material properties.

KEYWORDS: Particle tracking detectors (Gaseous detectors); Resistive plate chambers; Large detector systems for particle and astroparticle physics.

Contents

1. Introduction	1
1.1 Resistive plate chamber	1
2. Float glass characterization	2
2.1 Surface roughness	2
2.2 Elemental composition	2
2.3 Relative permittivity	3
3. RPC performance studies	3
3.1 Experimental setup	3
3.2 Results	4
4. Conclusions	6
5. Acknowledgements	6

1. Introduction

The India-based Neutrino Observatory (INO) collaboration has proposed to build a 50 kiloton magnetized Iron Calorimeter (ICAL) to detect the atmospheric neutrinos and antineutrinos separately. Main aims of the INO-ICAL experiment are to make precision measurements on the atmospheric neutrino oscillation parameters and address the fundamental issue of neutrino mass hierarchy. The INO-ICAL will consist of three modules of $16 \times 16 \times 14.5 \text{ m}^3$. Each module will have a stack of 151 horizontal layers of 5.6 cm thick iron plates interleaved with 4 cm gaps to house the active detectors. The experiment is expected to run for more than 10 years to record statistically sufficient neutrino oscillation data [1]. Layout of the proposed INO-ICAL detector, comprising of three modules is shown in Figure 1.

The INO collaboration has chosen $2 \times 2 \text{ m}^2$ size glass Resistive Plate Chambers (RPCs) as the active detector elements and is going to deploy 28,800 of them in the ICAL detector. It is proposed to use glasses from Asahi and/or Saint-Gobain for producing RPCs. Therefore, we performed systematic material property studies on the glass samples from these two manufacturers and compared the performances of RPCs built using these glasses.

1.1 Resistive plate chamber

Resistive Plate Chambers (RPCs) are gaseous detectors, which work on the ionization principle. They are simple to construct in large sizes, offer two-dimensional readout, provide good efficiency ($>90\%$) and time resolution ($\sim 1 \text{ ns}$). Therefore, they are used as the trigger and/or timing detectors in many high-energy physics experiments [2]. The basic construction scheme of a single gap RPC is shown in Figure 2.

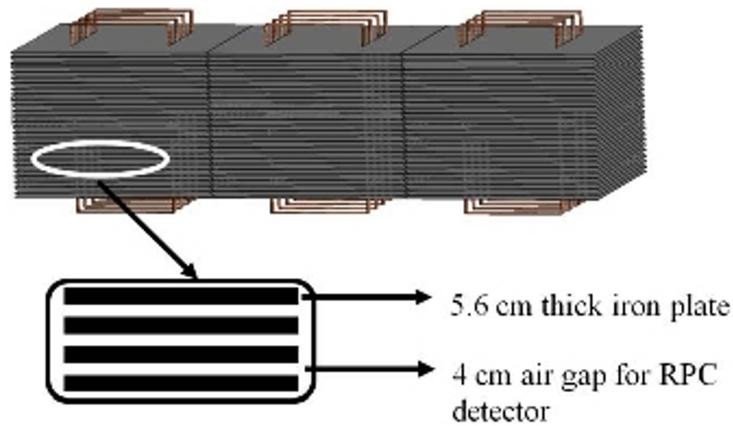


Figure 1. Layout of the proposed INO-ICAL detector.

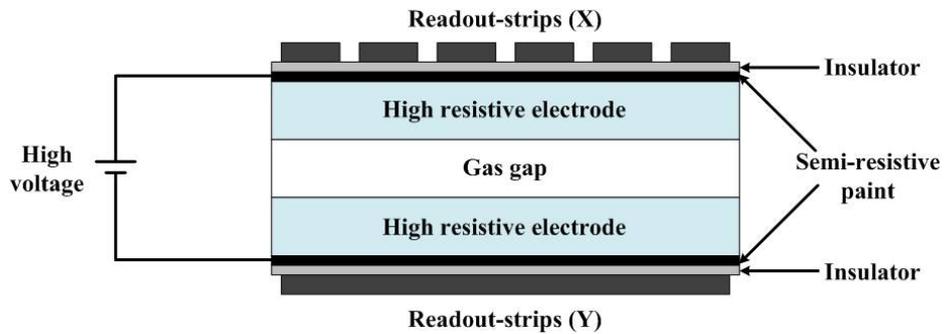


Figure 2. Basic construction schematic of a Resistive Plate Chamber.

2. Float glass characterization

2.1 Surface roughness

The inner surface of the electrode that is facing the gas volume should be as smooth as possible, so that the field emission of electrons from cathode can be minimized [3]. These emitted electrons increase dark current and singles rate of RPC and thereby deteriorating its performance. Therefore, the surface roughness of glass samples from Asahi and Saint-Gobain was measured using BRUKER ContourGT Optical Microscope. The microscope resolution is <0.01 nm. The surface roughness measurements are shown in Figure 3. The RMS surface roughness (R_q) values of the glasses are quoted below the image of each scan. Both the glasses showed identical surface roughness.

2.2 Elemental composition

Elemental compositions of the glass samples were measured using Energy Dispersive X-ray technique equipped with FEI Quanta 200 Scanning Electron Microscope. The results in fractional atomic percentages are summarized in Table 1. We observed that Asahi glass is showing larger Na component ($\sim 2\%$) compared to that of Saint-Gobain glass.

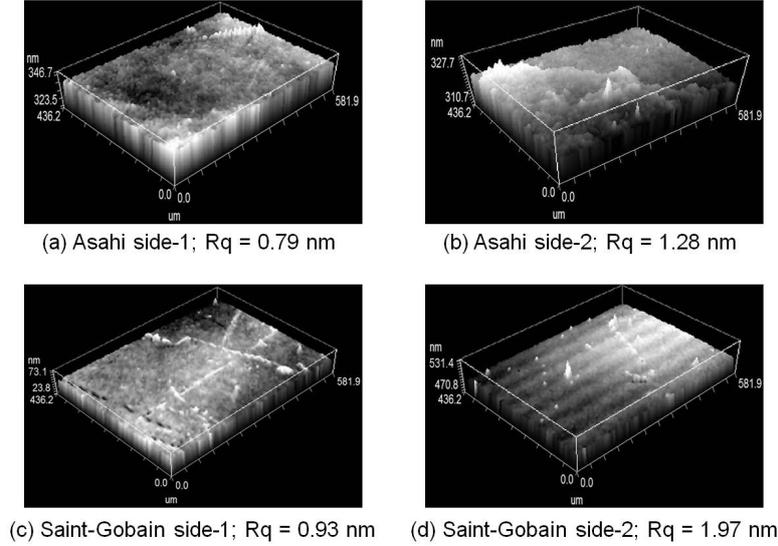


Figure 3. Surface roughness measurements of the glasses using BRUKER ContourGT Optical Microscope. Size of each scan is $582 \mu\text{m} \times 436 \mu\text{m}$.

Table 1. Summary of various elemental compositions of glass samples in fractional atomic percentages (%).

Element	Asahi (%)			Saint-Gobain (%)		
	Sample-1	Sample-2	Average	Sample-1	Sample-2	Average
Oxygen (O)	70.93	68.65	69.79	71.03	71.38	71.21
Silicon (Si)	15.43	16.69	16.06	16.7	16.86	16.78
Sodium (Na)	10.46	10.71	10.59	8.7	8.29	8.5
Magnesium (Mg)	2.21	2.51	2.36	2.17	2.31	2.24
Calcium (Ca)	0.48	0.82	0.65	0.85	0.6	0.73
Aluminium (Al)	0.48	0.56	0.52	0.46	0.52	0.49
Iron (Fe)	0.02	0.05	0.04	0.08	0.04	0.06

2.3 Relative permittivity

Relative permittivities of glass samples were measured using 'Novocontrol Broadband Dielectric/Impedance Spectrometer' at 20°C . We observed that the relative permittivity of Asahi glass is larger compared to that of Saint-Gobain glass as shown in Figure 4. This may be related to larger Na component in Asahi glass as shown in Table 1. In glass, the larger Na component leads to larger Na^+O^- ionic characteristic bonds. These bonds are more easily polarizable in an applied electric field, which leads to larger electric permittivity [4].

3. RPC performance studies

3.1 Experimental setup

RPCs of $30 \times 30 \text{ cm}^2$ size were built using 3 mm thick float glass plates from Asahi and Saint-

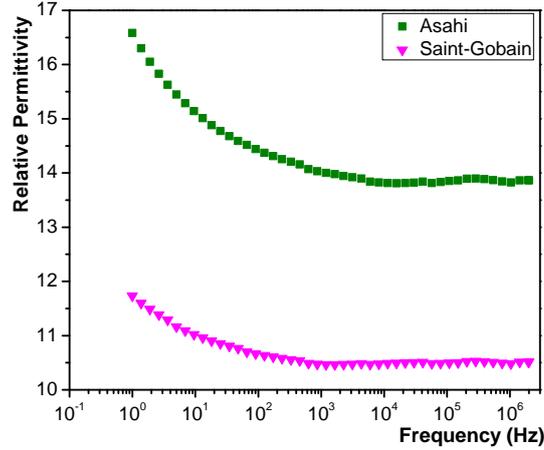


Figure 4. Relative permittivity measurements of Asahi and Saint-Gobain glasses using Novocontrol Broad-band Dielectric/Impedance Spectrometer.

Gobain manufacturers. The outer surfaces of the glass plates were coated with specially developed conductive graphite paint for the ICAL RPCs, which facilitates applying high voltage across the electrodes [5, 6]. The surface resistance of the electrodes was uniform ($\sim 1 \text{ M}\Omega/\square$). Readout-strips of 2.8 cm wide, with 0.2 cm gap between the consecutive strips, were orthogonally mounted on the external surfaces of the RPCs. A layer of mylar sheet was inserted between the electrode and the readout-strip. The gas gaps made out of Asahi glass and Saint-Gobain glass were named as A-RPCs and S-RPCs, respectively. A gas mixture of $\text{C}_2\text{H}_2\text{F}_4/\text{iso-C}_4\text{H}_{10}/\text{SF}_6 = 95/4.5/0.5$ was flown through the RPCs with a total flow rate of 10 SCCM and operated in the avalanche mode. All the RPCs were operated under identical environmental conditions.

A cosmic ray muon telescope was set up with three plastic scintillation paddles to get a 3-fold coincidence. The dimensions of scintillation paddles in length \times width \times thickness are $30 \times 2 \times 1 \text{ cm}^3$ (top), $30 \times 3 \times 1 \text{ cm}^3$ (middle), and $30 \times 5 \times 1 \text{ cm}^3$ (bottom). The RPCs were stacked between top and middle scintillation paddles. The experimental setup developed to test the RPCs is shown in Figure 5.

3.2 Results

Voltage-current characteristics:

The voltage-current characteristics of the RPCs were measured using C.A.E.N Mod. N471A, 2 channel HV Power Supply. The current resolution of the module is 1 nA. The currents drawn by the RPCs as a function of applied voltage are shown in Figure 6. A-RPCs were found to draw lower bias currents compared to S-RPCs. This is due to larger relative permittivity of Asahi glass compared to Saint-Gobain as shown in Figure 4. In an applied electric field, the larger relative permittivity material shows comparatively smaller leakage currents.

Efficiency studies:

The normal vector component of the electric field displacement is continuous at the electrode/gas

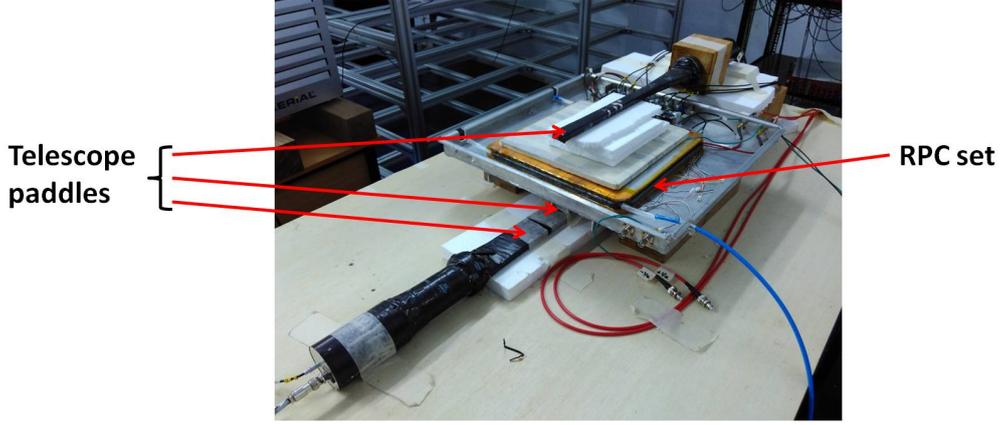


Figure 5. Experimental setup developed for characterizing the $30 \times 30 \text{ cm}^2$ size RPCs.

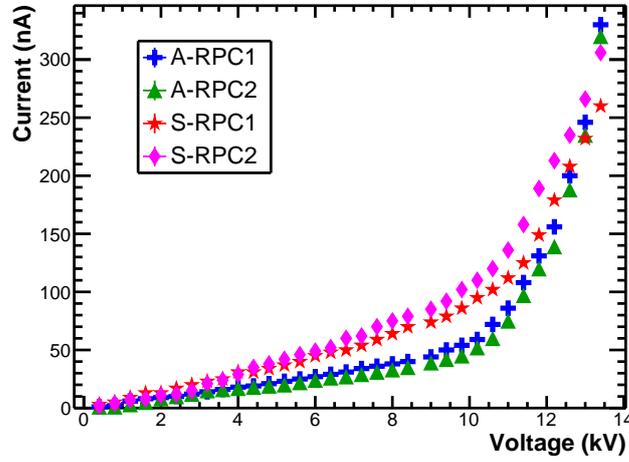


Figure 6. Currents drawn by the RPCs as a function of applied voltage.

interface of RPC. This boundary condition is expressed as:

$$\mathbf{D} = \epsilon_p \mathbf{E}_p = \epsilon_g \mathbf{E}_g, \quad (3.1)$$

where, ϵ_p and ϵ_g are the permittivities, and \mathbf{E}_p and \mathbf{E}_g are the electric fields of the electrode plate and the gas gap, respectively [7]. Equation 3.1 indicates that the RPCs made out of electrodes with larger relative permittivity can be operated at lower bias voltages.

Efficiencies of the RPCs were measured using cosmic-ray muons. The experimental setup is shown in Figure 5. We used C.A.E.N Mod. V830 Scaler for these measurements. The efficiencies of the RPC detectors were calculated using the formula:

$$Efficiency = \frac{4\text{-fold (4F) rate}}{3\text{-fold (3F) rate}} \times 100\%, \quad (3.2)$$

where, $3F$ is the telescope trigger signal, which is generated by time coincidence of three scintillator paddles, $4F$ is the coincidence signal of the RPC under test and the telescope trigger signal.

The efficiencies of RPCs as a function of applied high voltage are shown in Figure 7. All four RPCs showed more than 95% efficiency on the plateau. It is observed that the knee of efficiency plateau of A-RPCs starts at 10.8 kV, where as that of S-RPCs starts at 12.0 kV. Therefore, A-RPCs can be operated at 1.2 kV lower bias voltage in comparison to S-RPCs. As already mentioned above, this is due to larger relative permittivity of Asahi glass and hence these efficiency results are consistent with Equation 3.1.

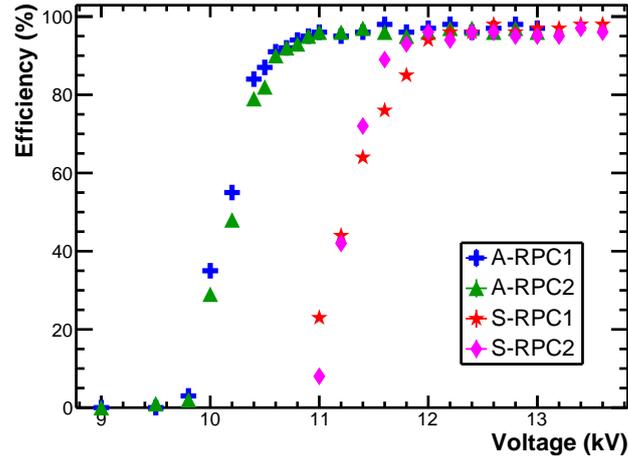


Figure 7. Efficiencies of the RPCs as a function of high voltage.

4. Conclusions

Systematic characterization studies were performed on the float glass samples from Asahi and Saint-Gobain. They showed identical surface roughness. From the elemental composition measurements, we observed that Na component of Asahi glass is larger ($\sim 2\%$) compared to that of Saint-Gobain glass. We conclude that this is the reason for higher relative permittivity of Asahi glass. RPC detectors were built using these glasses and their performances were studied. Asahi RPCs were found to draw lower bias currents compared to Saint-Gobain RPCs. The knee of efficiency plateau of Asahi RPCs and Saint-Gobain RPCs started at 10.8 kV and 12.0 kV, respectively. Therefore, our study indicates that the RPCs made from Asahi glass will be better suited for the INO-ICAL experiment.

5. Acknowledgements

This work was supported by the Department of Atomic Energy (DAE), and the Department of Science and Technology (DST), Government of India. The authors would like to gratefully acknowledge the help of their colleagues V. Asgolkar, S. Chavan, R. R. Shinde, V. M. Datar, N. K. Mondal at TIFR, Mumbai, and V. Janarthanam at IIT Madras.

References

- [1] Shakeel Ahmed et al., Physics Potential of the ICAL detector at the India-based Neutrino Observatory (INO), arXiv:1505.07380v1.
- [2] G. Bruno, Resistive plate chambers in running and future experiments, *Eur. Phys. J. C* 33, s01 (2004) s1032-s1034.
- [3] Changguo Lu, RPC electrode material study, *Nucl. Instr. and Meth. A* 602 (2009) 761-765.
- [4] Horst Scholze, *Glass: Nature, Structure, and Properties*, Springer-Verlag (1991).
- [5] R. Santonico and R. Cardarelli, Development of resistive plate counters, *Nucl. Instrum. and Meth.* 187 (1981) 377-380.
- [6] M. Bhuyan et al., Development of 2 m \times 2 m size glass RPCs for INO, *Nucl. Instrum. and Meth. A* 661 (2012) S64-S67.
- [7] M. Morales et al., Conductivity and charge depletion aging of resistive electrodes for high rate RPCs, 2013 JINST 8 P01022.