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Abstract

We report developments of the Microstrip Gas Chamber on thin-film Pestov glass and the Micro Gap Chamber. By coating a thin-layer of low-resistive, electronically-conductive glass on various substrates (including quartz and ceramics), we built MSGCs of high gain stability and low leakage current. They were tested in Ar-CH_4(10%) and He-C_2H_6(50%) gas mixtures. Energy resolutions of 17-20% were measured for 6keV x-rays. This design can make the choice of substrate less important, save the cost of ion-implantation, and use less glass material. Micro Gap Chamber was successfully tested in He-C_2H_6(50%) and Ar-C_2H_6(50%) gas mixtures. Energy resolutions of about 20% were obtained. Both detectors are expected to have high rate capability.

I. Introduction

The field of microfabrication of gas detectors has progressed rapidly since Oed introduced the Microstrip Gas Chamber(MSGC)[1]. Because of its good spatial resolution (about 30 μm for minimum ionizing particles [2]), excellent energy resolution (11% for ^{55}Fe x-rays[2]), and high rate capability (over 10^6 Hz/mm^2[2, 3]), the MSGC has found many applications such as charged-particle tracking and x-ray imaging. Gain instability has been the subject of extensive recent research and two approaches already exist for controlling gas gain stability effectively. One is to modify the surface conductivity by ion-implantation[2], the other is to choose an electronically-conducting substrate[3, 4]. Furthermore, Bellazzini recently introduced the Micro Gap Chamber (MGC)[5]. This new class of gas detectors (MGC) can have intrinsic gain stability and claim even better performance in charge-collection speed, spatial resolution, and rate capability than that of the MSGC[5].

In this paper, we describe our efforts in developing the MSGC on thin-film Pestov glass and the Micro Gap Chamber. Energy spectra of ^{55}Fe x-rays and gain dependences on anode and cathode voltages will be presented. We emphasize the fabrication aspects of the MSGC on thin-film Pestov glass and the Micro Gap Chamber and refrain from any discussion on rate capability or long-term stability until thorough studies have been completed.

II. Microstrip gas chamber on thin-film Pestov glass

The accumulation of positive ions on the insulator surface between anode and cathode is known to be responsible for gain instability in a MSGC. The time scale of ion recombination on the surface will therefore determine the rate capability of a MSGC. Systematic studies have shown that the higher surface conductivity, the higher rate capability [3, 4]. To have high surface conductivity, one can ion-implant the insulator surface[2] or use low-resistive, electronically-conducting substrate directly[3, 4]. A typical dosage of B-ion implantation on SiO_2 film is 4×10^{16} ions/cm^2 in order to make the MSGC stable[2]. This dosage is rather high and may be difficult to achieve for a large-scale application. The use of low-resistive, electronically-conducting substrate like the special Pestov glass[6] is straightforward. However, a large supply of this special glass is not typically available. The rather large leakage current is not desirable either. What is essential for MSGC's stability is, in reality, a surface layer with large electronic conductivity.

The technique of thin-film coating for MSGCs has recently been approached in various ways[7, 8, 9]. Very thin layers (2-20 nm) of semiconductive germanium were evaporated onto glass and plastic substrate[7]. Stable gains were observed for rates up to 10^5 mip/s/mm^2. However, it was not clear if oxidation of Ge would affect the performance and how to maintain uniformity of the thin film over a large area. Thin layers of nickel or chromium oxide were applied to MSGCs on plastic support[8]. Stable gain was obtained over a period of 30 days. Layers of 30-100 nm thick lead glass were also coated onto MSGCs on Desag glsss[9]. It was shown that lead glass coating could improve time-dependent stability and rate capability.

We chose to coat the Pestov glass on a substrate before making the microstrips. It has been demonstrated that low-resistive Pestov glass ($\rho = 10^9$ - $10^{12}\Omega\cdot$ cm) is an ef-

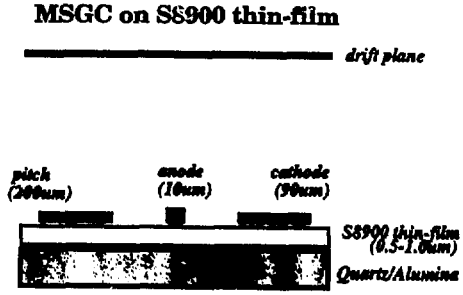

Figure 1: The structure of a MSGC on thin-film Pestov glass.

fective substrate material for making MSGCs[3, 4]. One advantage of coating Pestov glass is to reduce the leakage current significantly. Because of this, it is possible to use a Pestov glass of ρ less than $10^9\Omega\cdot$ cm and to push the rate capability up to the space-charge limit. Furthermore, the glass coating seems to be less sensitive to oxidation than Ge/Ni/Cr coating and the process is easier to control. The type of Pestov glass we used is S8900 supplied by Scott Glass Technologies (USA). Its bulk resistivity is $1.4\times10^{11}\Omega$-cm. (We expect to try Pestov glass of much lower resistivity in the future.)

A microstrip gas chamber was first constructed on bulk S8900 glass, and tested in an Ar-CH_4 gas mixture using a 100μCi ^{55}Fe source[10]. An energy resolution (FWHM) of 15% was achieved for 6keV x-rays. At a rate of 5×10^4 photons /sec/mm^2, the gas gain was stable within 3% for 2 hours. A gain of 1000 was obtained at 530 V. The behavior of leakage current vs. bias voltage was found to be ohmic, indicative of electronic conduction[10].

Figure 1 shows the structure of a MSGC on thin-film Pestov glass. It started with a pre-polished quartz wafer, ceramic plate, or Si wafer with insulator as mechanical support. Once cleaned, the substrate was loaded into the sputtering chamber. The target was a 5 inch disk of S8900 glass under water cooling. The sputtering process occurred in a low-pressure (6 mTorr) Ar plasma. The glass deposition rate was about 60A/min at 200W RF power and at 300sccm Ar flow. The thickness of S8900 glass thin film was typically 0.5-1.0 μm. After the coating, we fabricated Al microstrips on top of the S8900 glass layer. The widths of the anode and cathode strips were 10μm and 90μm, respectively. The anode-to-anode pitch was 200μm[10]. The measured leakage currents were less than 1nA at 500V bias and varied linearly as a function of the bias voltage.

Figure 2(a) shows the ^{55}Fe x-ray spectrum measured by a MSGC on thin-film Pestov glass on an alumina substrate in the Ar-CH_4(10%) gas mixture. The drift voltage was -200V and the cathode voltage was -490V, while the

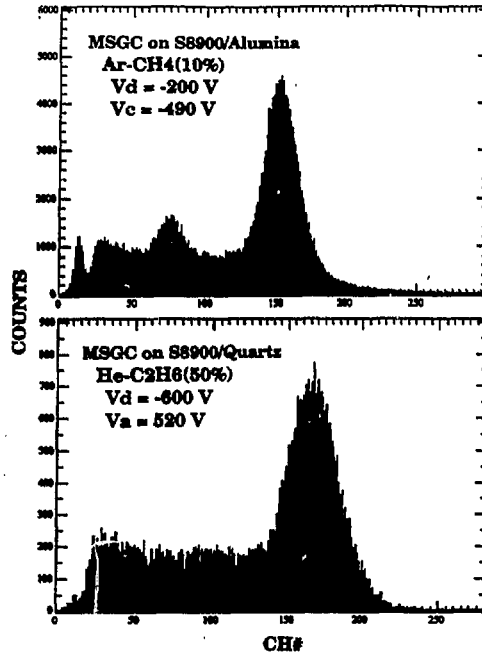

Figure 2: ^{55}Fe x-ray spectra measured (a) by a MSGC on thin-film Pestov glass on an alumina substrate in the Ar-CH_4(10%) gas mixture, and (b) by a MSGC on thin-film Pestov glass on a quartz substrate in the He-C_2H_6(50%) gas mixture.

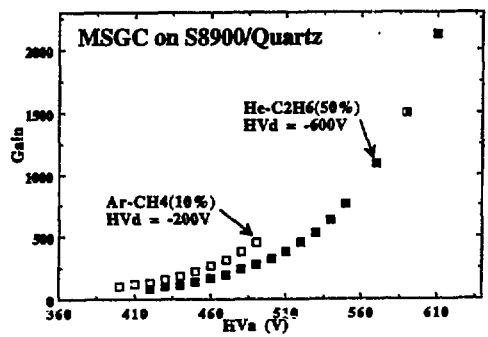

Figure 3: Gas gain dependence on the anode voltage for the MSGC on thin-film Pestov glass on a quartz substrate in two different gas mixtures.

anode voltage was at ground. This spectrum was taken with the ^{55}Fe source on for three hours at a rate of 50000 photons/sec/mm^2. Both the photo-peak and the escape peak are well resolved. The energy resolution (FWHM) was 17% at 6keV. The gain variation was less than 5% for over 3 hours. The flat background aside from the photo-peak and escape peak was due to incomplete charge collection since only four anode strips were connected together. Figure 2(b) shows the ^{55}Fe x-ray spectrum measured by a MSGC on thin-film Pestov glass on a quartz wafer in the He-C_2H_6(50%) gas mixture. The drift voltage was -600V and the anode voltage was 520V, while the cathode was grounded. Only a photo-peak is present. The energy resolution (FWHM) is 20% at 6kev. The slightly worse resolution was due to the fewer electron-ion pairs in a He gas mixture. It is known that the average ionization potential for He is 41eV and that for Ar is 26eV.

We measured the gas gain dependence on anode voltage for a MSGC on thin-film S8900 glass on quartz substrate shown in Figure 3. As expected, higher maximum gain can be obtained with more fraction of quenching gas. The maximum gain for the He-C_2H_6(50%) gas mixture is about twice that for the Ar-CH_4(10%) gas mixture. A MSGC built on thin-film S8900 glass on alumina substrate behaved similarly.

III. Micro gap chamber

The recently-invented Micro Gap Chamber (MGC)[5] represents a new class of gas detector that can be built with microfabrication techniques. Its radical design seemed to eliminate the problem with surface charging. It has been shown[5] that the speed of charge collection less than 10ns, the rate capability close to 10^7Hz/mm^2, and the spatial and energy resolutions similar to or better than those of a microstrip gas chamber. Since the electric field is very strong around the anodes (several MV/cm), we had concerns about the quality of SiO_2 film and the precision of anode-strip alignment. To understand these issues, we decided to build our micro gap chamber at the Berkeley Microfabrication Laboratory.

Figure 4 is the cross section of a finished micro gap chamber. We used a low resistive Si wafer as the cathode, a 2.5μm thick layer of SiO_2 as the insulator, and a 1.0μm thick Al film as the anode. The width of the insulator strip was about 30μm, and that of the anode strip was 10μm. The length of anode strip was 2.5cm. For simplicity, no segmentation was made in the cathode, and our design was conservative in comparison with that of Ref.[5].

Since the MGC has three dimentional structure, 2-3 masks are needed and the fabrication process becomes more involved. The first difficulty was alignment of the anode strip onto the insulator strip. As shown in the top picture of Figure 5, the asymmetric placement of anode strips gave rise to uneven electric field distribution and caused spark damage to the anodes. (It was recently shown

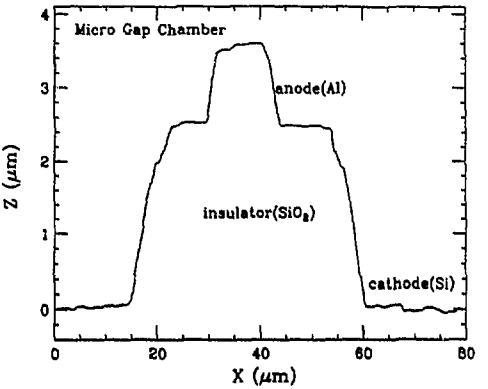

Figure 4: The cross-sectional view of a Micro Gap Chamber.

[11] that self-alignment of insulator strips with respect to anode strips is possible for 5μm thick SiO_2 film. This technique eliminates the alignment problem.) We also experienced difficulty with the SiO_2 insulator as shown in the bottom picture of Figure 5. A pinhole in the insulator may cause the anode to break under high voltage. To have high quality SiO_2 film, it is necessary to use low pressure chemical vapor deposition (LPCVD). A post-anneal at 800-900°C temperature would enhance the electric breakdown strength of SiO_2 insulator. In processing, we etched the anode strips first and the insulator strips second. Otherwise, we had difficulty in the step-coverage of the thick insulator strip with photoresist. Finally, an over-etch of insulator layer was necessary to ensure complete exposure of the cathode. Any residue film of SiO_2 would lead to instability after surface charging. Once the proper fabrication steps were taken, we were able to make Micro Gap Chambers of good quality.

As pointed out in Ref.[5], the MGC needs a larger fraction of quenching gas than the standard MSGC. We used a premixed bottle of Ar-DME(40%) from Matheson at the beginning. However, no photo-peak was measured even though the MGC operated stably. After suspecting the purity and homogeneity in DME-mixed gas, we switched to Ethane-mixed gas. Using premixed bottles of Ar-Ethane(50%) or He-Ethane(50%) from Matheson, we were finally able to operate our MGC smoothly.

We biased the cathode and read out the anode strips with a charge-sensitive preamplifier and shaping amplifier. Figure 6 shows ^{55}Fe x-ray spectra measured in the Ar-C_2H_6(50%) gas mixture (upper) and in the He-C_2H_6(50%) gas mixture (lower). An energy resolution of 20% (FWHM) was obtained. We also measured the gas gain as a function of the cathode voltage at a drift voltage of -1000V, as shown in Figure 7. The overall gain was less than 1000. We did not raise HV_c too high to avoid any spark damage, but the gain might be higher by several factors[11].

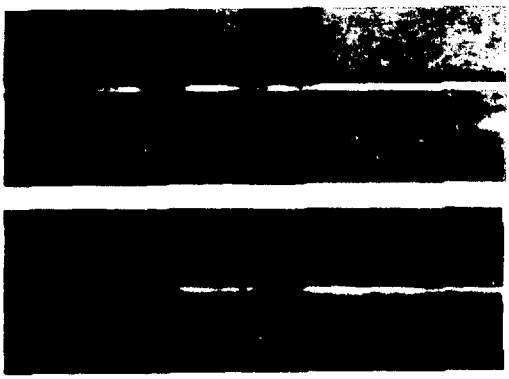

Figure 5: Photographs of discharge damages incurred due to (a) the misalignment of anode strips (top part) and (b) a pin-hole in the SiO_2 insulator layer (bottom part).

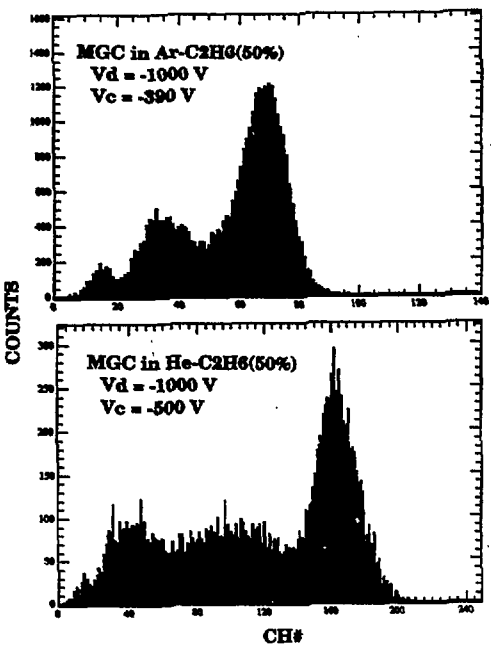

Figure 6: ^{55}Fe x-ray spectra measured by a MGC (a) in the Ar-C_2H_6(50%) gas mixture (upper), and (b) in the He-C_2H_6(50%) gas mixture (lower).

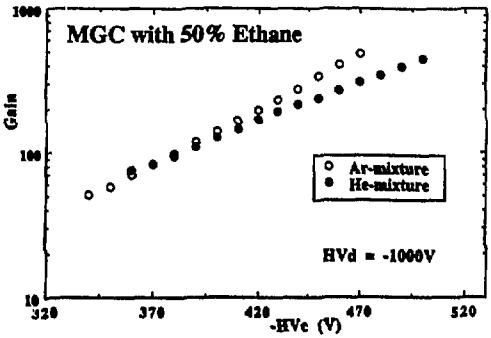

Figure 7: Gas gain dependence on the cathode voltage for a MGC in two different gas mixtures.

IV. Conclusions

In summary, we have worked on two types of gas detector using microfabrication techniques. The first gas detector is the Microstrip Gas Chamber on thin-film Pestov glass. By coating a thin-layer of low-resistive, electronically-conductive glass on various substrates (including quartz and ceramics), we built MSGCs of high gain stability and low leakage current. They were tested in Ar-CH_4(10%) and He-C_2H_6(50%) gas mixtures. Energy resolutions of 17-20% were measured for 6keV x-rays. This design can make the choice of substrate less important, save the cost of ion-implantation, and use less glass material. The second gas detector is the Micro Gap Chamber. We have overcome difficulties in strip alignment, SiO_2 film quality, and gas quencher while building our MGC. This experience helped us understand key issues in the design, fabrication, and operation of a MGC. We tested the MGC in the He-C_2H_6(50%) and Ar-C_2H_6(50%) gas mixtures. Energy resolutions about 20% were obtained, but further improvement should be possible.

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REFERENCES

[1] A. Oed, Nucl. Instr. and Meth. A263 (1988) 351.

[2] F. Angelini, et al. Nucl. Instr. and Meth. A315 (1992) 21.

[3] R. Bouclier, et al. Nucl. Instr. and Meth. A332 (1993) 100.

[4] Yu.N. Pestov and L.I. Shekhtman, Nucl. Instr. and Meth. A338 (1994) 368.

[5] F. Angelini, et al. Nucl. Instr. and Meth. A335 (1993) 69.

[6] A.R. Frolov, Yu.N. Pestov and V.V. Primachek, Nucl. Instr. and Meth. A307 (1991) 497.

[7] S. Brons, et al. Nucl. Instr. and Meth. A342 (1994) 411.

[8] M. Salomon, et al. Proc. IEEE 1993 Nuclear Science Symposium, San Francisco, Nov. 2-6, 1993, p.418.

[9] R. Bouclier, et al. Proc. IEEE 1993 Nuclear Science Symposium, San Francisco, Nov. 2-6, 1993, p.413.

[10] W.G. Gong, et al. IEEE Transaction on Nuclear Science, August 1994 (in print).

[11] F. Angelini, et al. INFN-Pisa/AE 94/01, March 19, 1994.