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RATE AND LIFETIME CHARACTERISTICS OF A GAS MICROSTRIP DETECTOR FABRICATED ON SPUTTERED S8900 GLASS

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The rate and aging characteristics of a gas microstrip detector fabricated on a thin film (800nm) of semiconducting glass (S8900) supported on a 1.1mm substrate of barium-alumina-borosilicate glass (Corning 7059) are reported.

1. INTRODUCTION

Following the introduction of the gas microstrip detector (GMSD) by Oed [1], we have studied a wide range of substrate and processing options for the construction of detectors which could show the rate and lifetime properties required by the demanding conditions likely to be met in LHC tracker facilities [2,3,4,5]. In our early work we found that semi-insulating substrate materials which depended on ionic conduction mechanisms (such as borosilicate glasses) are unstable in respect of rate and lifetime performance. On the other hand, we found that the use of an electronic semiconducting glass (such as Schott S8900) as the substrate produced unconditionally stable detectors which, with attention to the processing methods and to the gas system offer the prospect of a useful lifetime long enough for the hostile conditions of LHC. The principal drawback of S8900 glass is the high mean atomic number of the constituents which leads to a radiation length almost half that of a borosilicate glass. It is also a mechanically poor material so that handling sheets of thickness around 100μm (necessary to keep the scattering to an acceptable level) is foreseen to be a serious problem. The use of a sputtered layer of semiconducting material on top of a thin supporting substrate of a stronger (high resistivity) glass is an attractive approach to achieving an adequate surface conductivity ($< 10^{15}$ ohms/square) simultaneously with a low Z, high strength substrate.

Our first attempts at this approach used a standard material for the production of thin film resistors, viz. TaO_x (mixed oxides of tantalum) grown with chemical vapour deposition (CVD) on borosilicate substrates before the microstrip formation processes. This process was successful in producing surface resistances controllable between 10^{15} and 10^{13} ohms/square which were purely resistive and showed no time-dependent effects. GMSDs were fabricated on these surfaces using our standard metallisation pattern (10 micron anode widths with 100 micron anode-cathode gaps and a 90 micron wide cathode); the metal was aluminium. The detectors were successfully operated at gains of >1000 and the rate and lifetime characteristics examined. The main finding was that the gain rises rapidly under irradiation at quite modest levels until the counter finally sparks destructively. Annealing of the TaO_x surfaces in a controlled atmosphere improved the performance substantially; however, even the best sample showed gain instability with accumulated charge densities of only tens of microcoulombs/cm of anode and we concluded that a better prospect might lie in the use of the semiconducting glass (successfully used in bulk) as the sputter coating. We reasoned that perhaps the conductivity of a sputtered glass surface is less sensitive to modification by the contaminants introduced by the avalanche process than that of a surface produced by CVD. (The CVD process is known to produce a porous surface with dangling chemical bonds which can react with avalanche products.) In this we follow Gong et al [6] who report success with GMSDs fabricated on an alumina sustrate coated with S8900 glass before metallisation. Other workers have used sputtered under-coatings of lead silicate [7,8] over-coatings (applied after metallisation) of nickel oxide [9] and over-coatings of both semiconducting glass and polymers [10].

2. DETECTOR FABRICATION

The substrate used (50mm x 50mm) was alkali-free Corning 7059 (very high resistivity, barium-alumina-borosilicate glass). The S8900 coatings were done with a 4 inch rf-magnetron sputter using a power of 150W. A process time of 1 hour is estimated to have laid down

800nm of the S8900 glass. The sputtering ambient was chosen to be argon with 30% hydrogen. The sputtering distance was 57mm and the substrates were stationary and set directly below the magnetron target. This arrangement is known to produce non-uniformity in film thickness and, in the case of reactive compound sputtering, in stochiometry as well. However, for our preliminary tests this approach was considered adequate.

Table I shows the details of the five plates coated (CI - CV) in this way. Plates CI, CII and CIII were coated identically (800nm thickness); the coating on plate CIV was reduced to 200nm and in the case of plate CV the sputtering gas pressure was reduced from 10mtorr to 3mtorr.

The detector plates were fabricated using a standard test mask. The anode width is 10μm, the cathode width 90μm and the anode cathode gap is 100μm. Twenty anodes (and cathodes) of 16mm active length are bussed together giving a 6mm active width. The pattern is repeated seven times on a plate of overall dimensions 50mm x 50mm. The metallisation is either aluminium (plates CI, CIV, CV), titanium/gold (plate CII) or nickel/gold (plate CIII). The aluminium metallisation was sputtered-coated onto the substrates to a thickness of 500nm and then patterned using wet etching with a photoresist mask. The Ni/Au strip pattern was formed by first sputter coating the plate with a 100nm thick layer of nickel and electroplating the 500nm thick gold pattern through the openings in a photoresist onto the nickel. A similar procedure was used for the Ti/Au metallisation.

All coating and microstrip fabrication procedures were carried out at VTT Electronics.

3. EXPERIMENTAL SET-UP

The lithographic plate was supported on structures of standard glass-epoxy circuit boards housed in an aluminium box with a rubber seal and an aluminised melinex window (50μm) for xray access. Electrical leadthroughs are standard SHV connectors sealed with epoxy. The drift electrode was spaced at 10mm from the lithographic plate.

A gas mixture of argon with 17%DME was supplied by our "clean" gas mixing system as described in reference [5].

We used the electronics readout system described in reference [5] and the same calibration procedures for the gain and the rate. The same xray test beam was used which can deliver $>10^6$ 8keV xray events per second into a spot 1mm diameter.

The bias conditions for rate and aging tests were as follows: Drift potential = -3.0kV (over 1cm drift space) and Cathode potential = -545V.

The conductance of each of the seven sections of a detector was measured by plotting the I/V curve of a section using a Keithley Picoammeter. The known geometry of a section then permitted the surface resistance to be calculated in ohms/square (there are 6400 squares in a section).

4. RESULTS

A survey of the conductances of a plate showed that (as expected) the sputtering process has not produced a coating of uniform thickness (circular interference patterns visible to the eye confirm this). Figure 1 shows the measured conductance values of the seven detector sections for the four plates sputtered with S8900 glass to a thickness of 800nm. The three plates sputtered at 10mtorr (CI, CII, CIII) show a consistent pattern with a dip in the centre of the plate, while the sample sputtered at 3mtorr (CV) shows a peak in the centre. It seems clear that even with the stationary 4 inch target the S8900 coating process could be tuned to yield an acceptably uniform surface conductance by adjusting the sputtering pressure to an intermediate value.

In order to assess the surface conductivity (resistivity) achieved we consider section #1 of plate CIII which we used for our lifetime tests. Taking the maximum conductance value (section #1) of 1.43 pS to correspond to a coating thickness of 800nm, one deduces resistivity values of 3.6 10^{11} ohm-cm and 4.5 10^{15} ohms/square. Our estimate of the bulk resistivity of our sample of S8900 glass is 1.3 10^{11} ohm-cm. It is no surprise to find the resistivity of the sputtered layer higher than that of the bulk material, although the uncertainty in the thickness of the sputtered layer means that only order-of-magnitude agreement can be expected. The I/V curves from which the conductance values are derived are exactly linear and show no time-dependent effects.

Plates CI, CII and CIII all show a similar pattern of conductance variation with a symmetric pattern (which fits to an inverted gaussian) showing a minimum conductance in the centre which is approximately 5% of the conductance of the end sections. (The maximum and minimum conductances of the end sections of these three plates all lie within a factor of two.) Plate CV which was processed with a lower gas pressure shows an inverted pattern with a maximum conductance of 2.5pS in the centre of the plate.

All sections with conductances greater than approximately 0.5pS operate well as counters. Figure 2 shows the gas gain and the FWHM (full width at half maximum) as a function of position along section #7 as measured from the PHA (pulse height analyser) spectrum of 8keV xrays detected in a GMSD which uses plate CI. While the gain uniformity and the FWHM do not compete with the specification realised by a detector made with bulk S8900, the performance is quite good enough for the majority of applications. There is no sign of any pattern in the gain matching the circularly symmetric modulation of the conductance.

Experience with GMSDs fabricated on bulk S8900 showed transient effects of rate change on the gain of a few percent with time constants of about ten seconds. The GMSDs made with S8900-sputtered glass show a stronger effect. As figure 3 shows, a gain rise of around 15% is observed between resting and a count rate density of 15kHz/mm^2. The slow decline at higher rates is attributable to positive ion drift effects. The chief time constant involved is around ten seconds (as in bulk S8900). A small residual effect (about 2% in the gain) has a longer time constant of around 10 minutes.

For lifetime testing the xray beam was applied to a constant spot in the middle of a detector section for prolonged periods. At a gas gain of ≈ 1000 the GMSDs fabricated from the sputtered plates exhibited stable operation up to count-rate densities approaching

200kHz/mm^2, so for the lifetime tests a value of 115kHz/mm^2 (8keV xrays) was chosen which delivered a charge dose of 1.4mC/cm of anode per day of exposure. At regular intervals a copper attenuating foil was inserted in the xray beam, reducing the rate to $\approx$4.2kHz and the peak position, the peak FWHM, the ambient pressure and the ambient temperature recorded. (A delay of about 30 seconds was required before taking the reading to allow the transient effect noted above to settle.) The pressure and temperature readings were used to correct for gain changes induced by ambient fluctuations. At intervals of about 10mC/cm in the exposure programme, a scan of the gain and FWHM was made across the locus of the beam spot.

Figure 4 shows the relative gain measured in the above manner for plate CI (Al metallisation) and CIII (Ni/Au metallisation) out to an accumulated dose of 105mC/cm ($\approx$80 days exposure). In accordance with our experience with GMSDs utilising Al metallisations on bulk S8900, we observed a rapid gain decline at relatively low accumulated charge dose. On the other hand the plate metallised by the Ni/Au process showed an excellent aging performance with a gain loss of $\approx$15% at 105mC/cm.

Scanning across the irradiation site (figure 5) shows that the pattern of gain loss is a simple dip centered on the beam position. Normalisation of the post-irradiation scan to a pre-irradiation scan is made difficult by an apparent long-term drift of the gain in this detector by $\approx \pm 5\%$. The flattening of the outer portions of the gain curve in the post-irradiation case indicates that there is also a small gain modulation with a FWHM of $\approx$10mm in addition to the dip which is approximately equal to the beam diameter (1mm).

In our experience the deterioration of the pulse height spectrum (i.e. the FWHM) of the xray peak is a reliable diagnostic of aging problems in a GMSD. It is a feature of the results from plate CIII that the pulse height spectrum is indistinguishable from its pristine shape at 105mC/cm and shows no time-dependent effects when the detector is rested. (In the course of the irradiation schedule the detector has been rested for periods of up to two weeks on several occasions.)

4. DISCUSSION

We are much encouraged by the results of our first tests with GMSDs fabricated on barium-alumina-borosilicate glass substrates with a sputtered coating of S8900 semiconducting glass. Stable, reliable detectors have been fabricated which, at a current charge dose of 105mC/cm show a gain drop of 15% (initial gain = 1000) with no deterioration in the pulse height spectrum. The exposure will be continued to $\approx$120mC/cm and will, we anticipate, demonstrate the lifetime required for LHC operation.

We have not yet been able to characterise the coatings produced. However, the superficial resistivity produced in the working areas of the plates is only approximately three times that of the estimated bulk resistivity of S8900 indicating that the composition of the coating is not very different from that of the bulk material. (Thin film coatings in general show increased resistivity relative to their native, bulk material.) The uniformity achieved in the initial coatings is clearly inadequate: a factor of two or three variation in the resistivity would be quite acceptable and this should be quite technically feasible, as noted above. We are also

working to be able to sputter substrates of larger area: initially our standard 100mm x 100mm plates, but eventually larger sizes. The prototype plates show an enhanced gain versus rate effect compared to bulk material and while this is not, we believe, a serious defect an aim of future development would be to return to the smaller effect exhibited by bulk S8900.

As well as extending the area of the sputtered plates we intend to sputter semiconducting glass onto thin borosilicate glass, e.g. 200μm thick D263. The performance of a GMSD fabricated with a thin substrate fitted with a back electrode and operated in a high drift field showed very promising lifetime performance, only degraded by the sensitivity of the D263 to long-term ion drift effects [11,8,12]. Such a structure fabricated with a thin substrate sputtered with semiconducting glass could well offer the prospect of a GMSD with outstanding aging characteristics as well as a very low fraction of a radiation length.

We also propose to examine the properties of plates sputtered with the semiconducting glass of 10^9 Ω-cm resistivity (developed by our collaborator Yu N Pestov) which we have already used successfully in bulk form [5].

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TABLE I

Plate ID	Sputtering Gas Pressure mtorr	Coating Thickness nm	Strip Metal
CI	10	800	Al
CII	10	800	Ti/Au
CIII	10	800	Ni/Au
CIV	10	200	Al
CV	3	800	Al

FIGURE CAPTIONS

Figure 1.
Survey of the section conductances on the plates sputtered with S8900 glass to a thickness of 800nm.

Figure 2
The gas gain and pulse height resolution variations along the length of section #7 of plate CI (as measured by 8keV xrays).

Figure 3
The gain shift with count rate density as measured on section #7, plate CIII.

Figure 4
The relative gain change as a function of accumulated charge dose (mC/cm of anode) in counters fitted with plate CI (Al metallisation) and CIII (Ni/Au metallisation).

Figure 5
A gain scan across the irradiated site on plate CIII before and after prolonged irradiation.

FIGURE 1

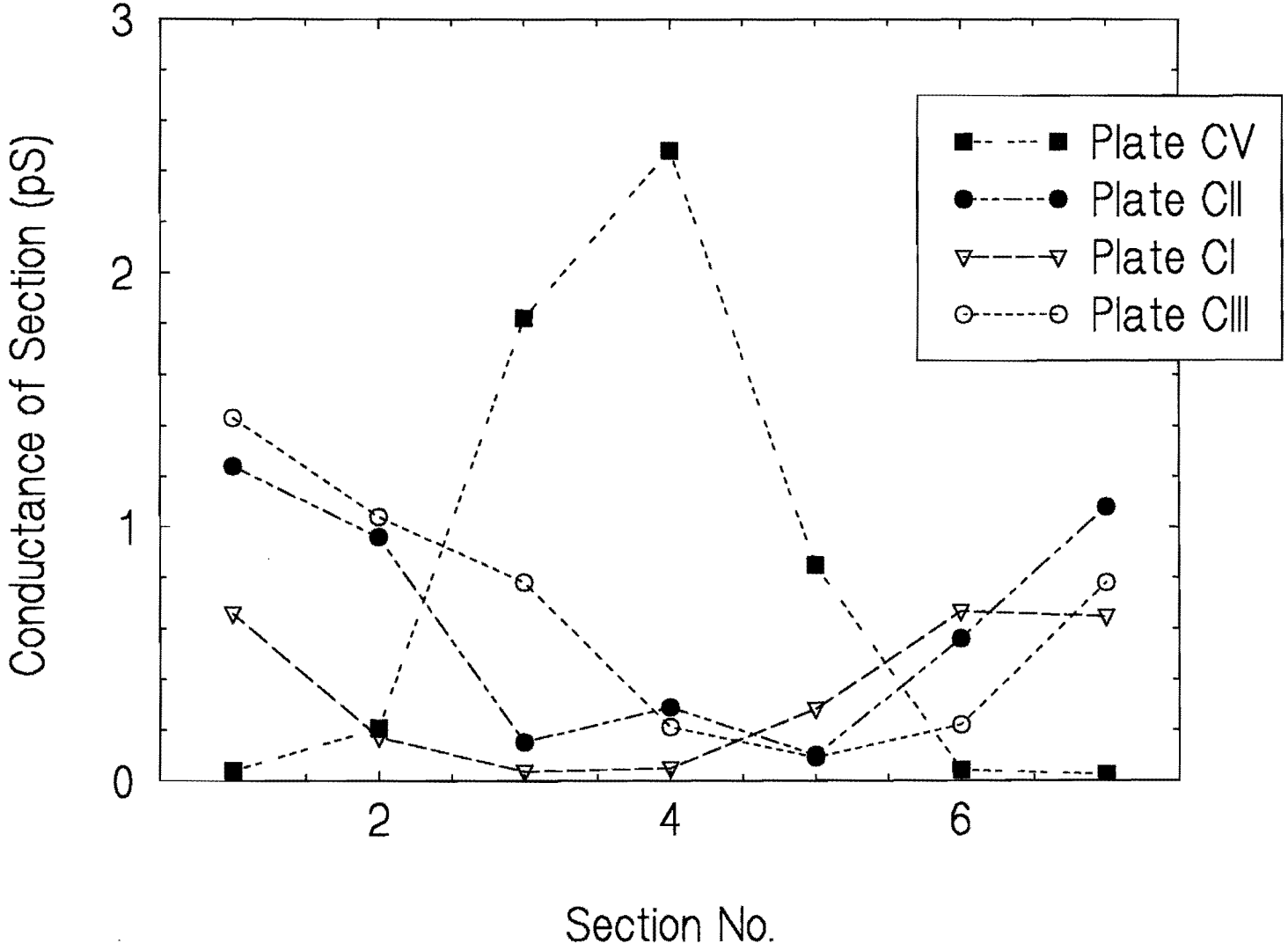

Conductance of Section (pS)
3
2
1
0
2
4
6
Section No.
Plate CV
Plate CII
Plate CI
Plate CIII

FIGURE 2

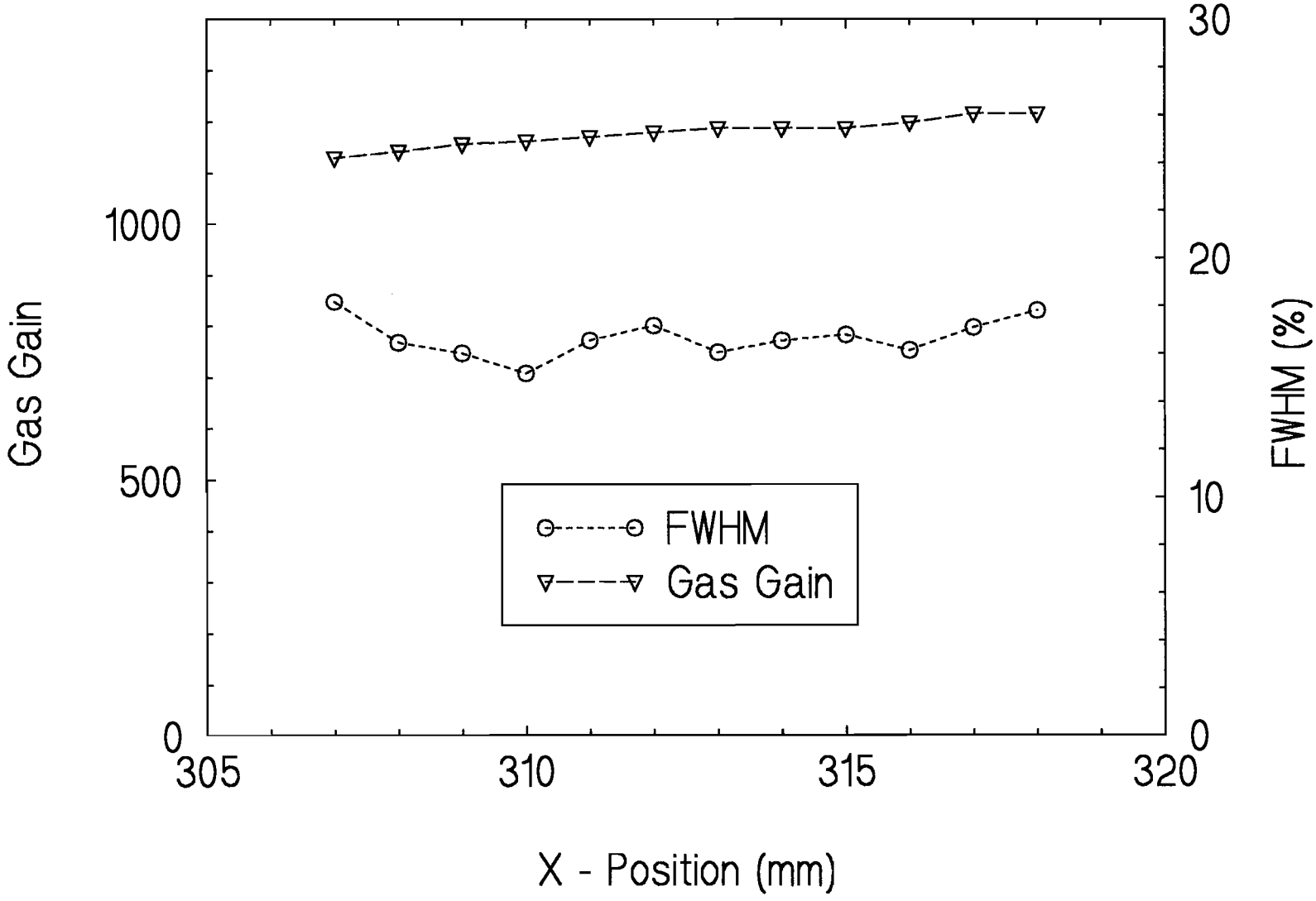

Gas Gain
1000
500
0
305
310
315
320
30
20
10
0
FWHM (%)
FWHM
Gas Gain
X - Position (mm)

FIGURE 3

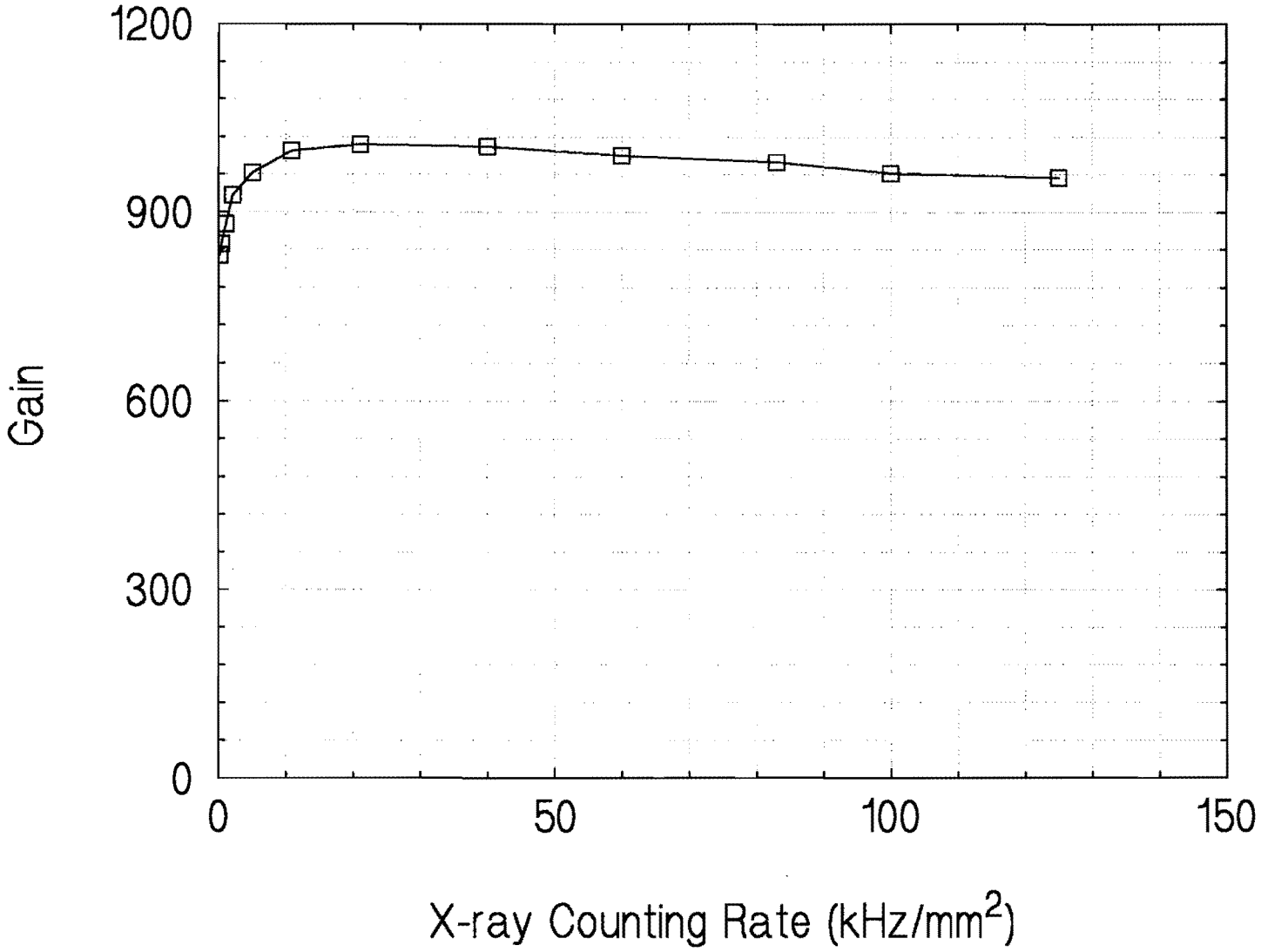


FIGURE 4

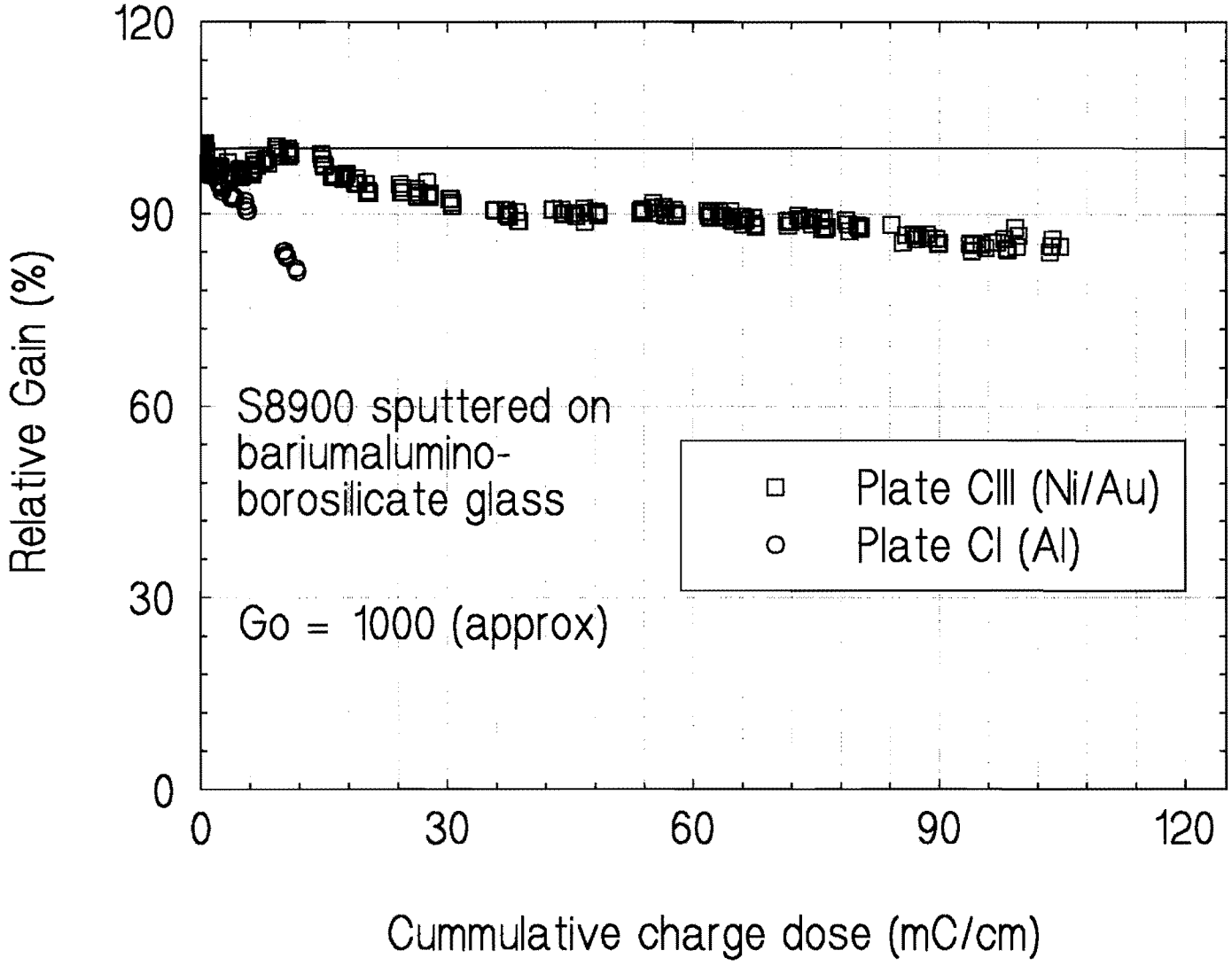
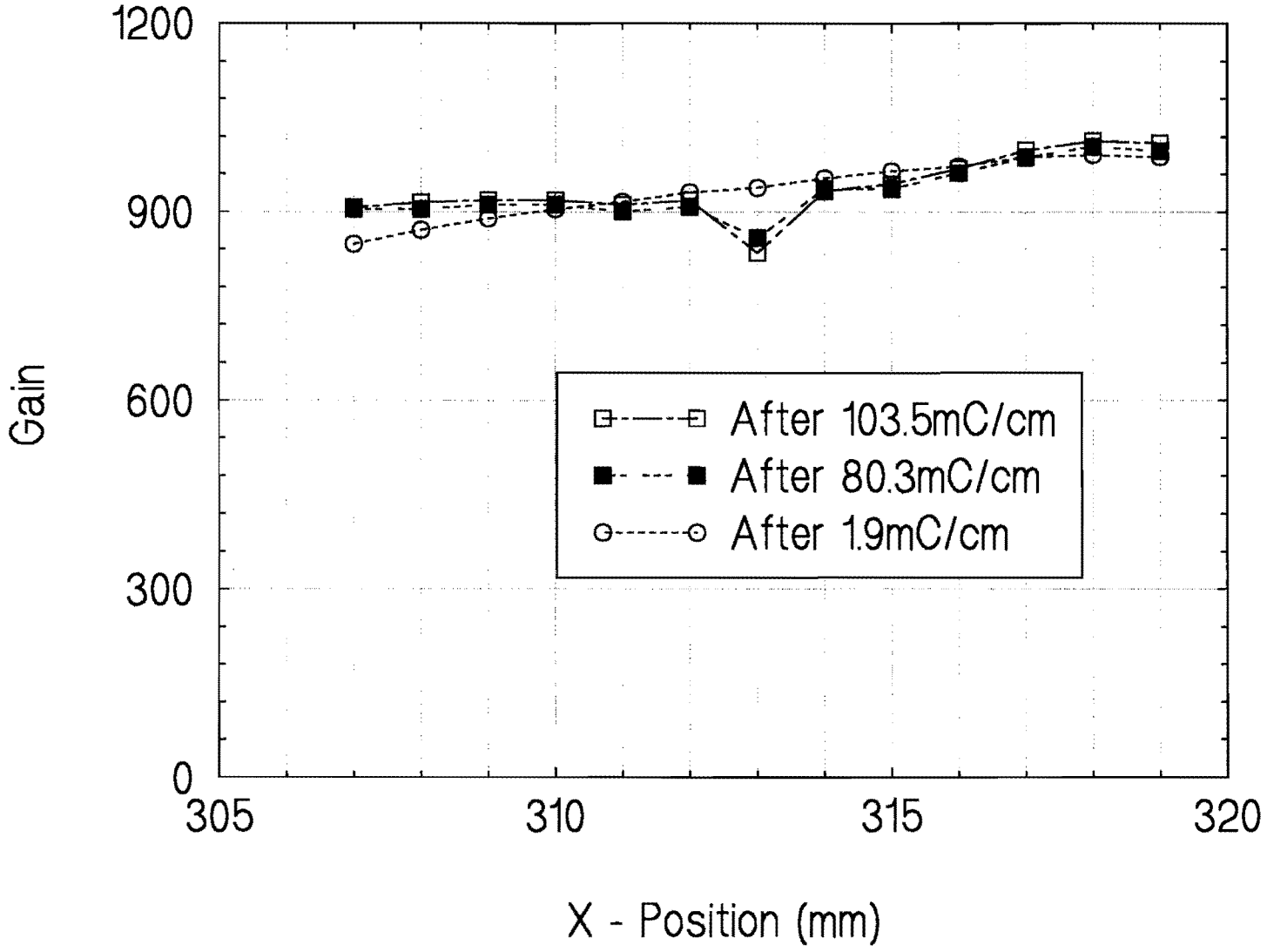

120
90
60
30
0
0
30
60
90
120
Relative Gain (%)
Cummulative charge dose (mC/cm)
S8900 sputtered on
bariumalumino-
borosilicate glass
Go = 1000 (approx)
Plate CIII (Ni/Au)
Plate CI (Al)

FIGURE 5


1200
900
600
300
0
Gain
305
310
315
320
X - Position (mm)
After 103.5mC/cm
After 80.3mC/cm
After 1.9mC/cm