

Fermi National Accelerator Laboratory

FERMILAB-Conf-94/307

Low-Pressure Micro-Strip Gas Chamber and a Search for a High-Efficiency Secondary-Electron Emitter

D.F. Anderson and S. Kwan

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

C. Sbarra

*INFN-Pisa, Via Livornese 582
I-56010 S. Piero a Grado, Pisa, Italy*

November 1994

Presented at the *4th International Conference on Advanced Technology and Particle Physics*,
Como, Italy, October 3-7, 1994



Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

(Presented at the 4th International Conference on Advanced Technology and Particle Physics in Como, Italy, October 3-7)

Low-Pressure Micro-Strip Gas Chamber and a Search for a High-Efficiency Secondary-Electron Emitter

D.F. Anderson^a, S. Kwan^a, and C. Sbarra^b

^aParticle Detector Group
Fermi National Accelerator Laboratory
Batavia, IL 60510, USA

^bINFN-Pisa, Via Livornese 582
I-56010 S. Piero a Grado, Pisa, Italy

The test beam performance of a low-pressure micro-strip gas chamber with a thick CsI secondary-electron emitting surface as the source of primary ionization is presented. A study of the secondary-electron yield of CsI and KCl coated surfaces are discussed, as well as a promising new technique, CsI-treated CVD diamond films.

1 INTRODUCTION

There is currently a great deal of activity in the development of micro-strip gas chambers, MSGC, for tracking in high energy physics. (See ref. [1-3] and references therein.) Their attractions are: position resolutions as good as 30 μm for particles at normal incidence, a rate capability of up to $10^6 \text{ s}^{-1} \text{ mm}^{-2}$, and radiation hardness. The MSGC also lends itself to the coverage of large areas.

There are shortcomings of the conventional MSGC. The typical gas gain is only 3000. Also, the collection of the charge liberated across a 3 mm gap yields a collection time of 50-70 ns, requiring shaping times of the low-noise amplifiers to be 40-50 ns in order to maintain high efficiency. Although a timing resolution of 7 ns rms has been achieved [2], resolutions of ≥ 17 ns are more typical [3].

Another difficulty for MSGC is that their single-strip efficiency, position resolution, and timing resolution degrade rapidly with increasing angle of incidence. In one study [4] the single-strip efficiency of 98% at 0° degraded to 35% at 30°, and the position resolution of 40 μm at 0° degraded to 300 μm at 30°.

To address many of these problems we proposed and demonstrated the use of low-pressure MSGC using secondary-electron, SE, emission from a surface as the source of ionization[5]. With this approach, we have been able to increase the gas gain to $>10^5$, improve the timing resolution to better than

0.9 ns, and achieved a reduced sensitivity to discharges. The positive-ion collection time was also reduced to less than 300 ns. In principle, this technique also eliminates dependency of position resolution, single-strip efficiency, and timing resolution on the angle of the incident particle

2 TEST BEAM MEASUREMENTS

A measurement was made of a low-pressure MSGC in the M13 beam line at TRIUMF [6]. The details of the chamber are described in greater detail elsewhere [5]. The SE emitter was 10 μm of CsI on a Si substrate and the MSGC operated with a filling of 20 Torr of isobutane. The beam consisted primarily of pions and electrons with a momentum of 300 MeV/c. The trigger selected particle in a $5 \times 5 \text{ mm}^2$ area on the face of the detector, and measurements were made at angles of 0°, 15°, and 30°.

Due to the lack of tracking, the position resolution of the low-pressure MSGC was not measured. We were able to demonstrate that the efficiency did not change with angle. For signals 2σ or greater above the pedestal the efficiencies were 8.9%, 8.3%, and 8.3% for 0°, 15°, and 30°, respectively. The small differences in the efficiencies with angle are within the anticipated standard deviation of 0.5%. These measurements do show that the efficiency of the device is not angle dependent.

After the test the SE emitter was tested in the lab and found to have an efficiency of 17%. The discrepancy is believed to be due to the higher sensitivity of the amplifier used in the laboratory and because the signal in the laboratory was developed on a single electrode rather than on several anodes in the MSGC.

One feature of the low-pressure MSGC is that the charge amplification develops primarily across the gap rather than in a small volume around the anode, and most of the positive ions are collected by the SE emitter rather than the adjacent cathode strips. Thus the signal is seen by more than one anode and potentially would allow a center-of-mass readout to yield a position resolution better than the pitch of the electrodes. The mean number of anodes that developed a signal per event were 2.70, 2.84, and 2.85 for 0° , 15° , and 30° , respectively. For all three angles about $70\% \pm 13\%$ of the total signal was seen on the channel with the highest signal.

3 SE EMISSION

The key to making the low-pressure MSGC a viable device is the discovery of a high-efficiency, SE emitter. To date the best SE emitter has been porous CsI. In our earlier work we achieve an efficiency of 17% for a porous CsI emitter operated in a low pressure chamber with an additional 4% contributed by the interaction of the minimum-ionizing particle with the gas[5]. For truly non-porous CsI the efficiency is only 2-3%[7]. Here we will present the results of our search for an improved SE emitter.

3.1 Experimental Procedures

The experimental setup used for our SE emission measurements is shown in fig. 1. Following the work of Chechik et al. [7], we constructed a chamber with Kapton entrance and exit windows. The substrate (usually an n-type Si wafer) with the SE emitter was attached to the first of three meshes by conductive paint. A copper guard with a hole in it was placed on the first mesh to insure that the only path that the beta particles could take was through the SE emitter. The emitter-to-second-mesh distance (grid1-grid2), the amplification region, was 2.1 mm, with a 10 mm second-to-third-mesh distance (grid2-grid3). All measurements were made with a gas filling of 10 Torr of ethane to minimize the interactions of the charged particles with the gas. The third grid was kept at the same potential as the second grid. This was to keep the

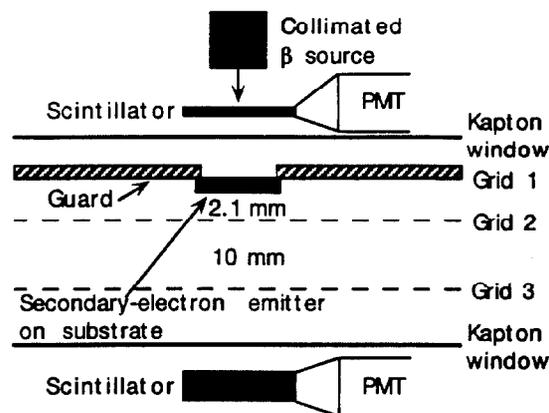


Fig. 1. Experimental setup used for secondary-electron emission measurements.

electrons that are liberated in the gas, outside of the amplification volume, from contributing to the signal. The measured efficiency for the gas in the amplification region was 2-3%. All of the measurements were made with a sealed chamber, without gas flow.

A collimated, Sr-90 beta source was used to provide the minimum ionizing particles. The higher-energy beta particles were selected by a coincidence of entrance and exit scintillation counters. For some measurements a 1.6 mm thick piece of printed-circuit board was placed between the chamber and the second scintillator to assure that only the highest energy beta particles were selected. The coincidence rate was lower in these measurements but the efficiency agreed well with the measurements made without this absorber. The measurements reported here were made without this absorber.

3.2 CsI and KCl SE Emitters

The most efficient SE emitters are the alkali halides, which have been studied extensively[7-10]. Fig. 2 shows our measurement of the efficiency of CsI and KCl surfaces as a function of thickness. The gas efficiency has been subtracted from the data. One set of CsI data was measured with the CsI deposited directly on a Si wafer. The other set of data was taken with the CsI deposited on a fresh 20\AA thick layer of Cs metal. What is clear is that the efficiency of the CsI coating saturates with thickness at about 16%. For some unexplained reason the efficiency for the CsI on the Cs surface gave a lower yield than for the CsI on the Si for the thinner

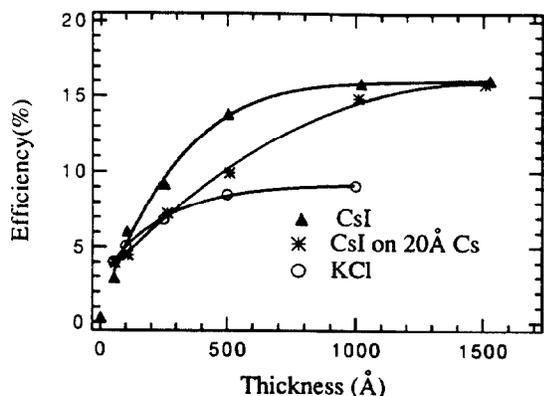


Fig. 2. Detection efficiency of CsI and KCl surfaces as a function of thickness.

coatings. The efficiency of the KCl coatings saturated at about 9%. This lower efficiency is consistent with the reduced secondary-electron range in KCl [11].

The efficiencies of porous CsI and KCl coatings were also studied. These were produced by depositing the material in 5 to 7 Torr of argon gas. The 10 μm thick porous-CsI coating gave an efficiency of 45% which was stable with time under normal operating conditions. The 10 μm thick porous-KCl coating degraded rapidly with time, dropping from 30% to 7% in about 30 minutes.

3.3 Diamond as a SE Emitter

In the search of a SE emitter with high efficiency, we were lead to the study of chemical vapor deposited, CVD, polycrystalline diamond films by two facts: 1) diamond is an insulator in which free charge can be transported easily [12-14], and 2) with the right surface treatment it has been shown (in vacuum) that the surface can be made to have a negative electron affinity [15-17]. So in principle, electrons liberated by a traversing charged particle should drift in an electric field in the diamond and exit the material into the gas to be detected. The negative electron affinity of diamond has been shown to be produced by the termination of the surface bonds with such materials as hydrogen [15, 16] or with a thin coating of titanium [17].

Almost all measurements of SE emission from diamond have been made in a high vacuum, and made by low-energy (few keV) electron bombardment of the diamond surface. A typical measurement of SE emission yield as a function of

incident electron energy for diamond [18] is shown in fig. 3 along with a similar measurement for CsI [19]. Both measurements were made in a high vacuum with low-energy electron bombardment of the emitting surface and had maximum yields of greater than 10 emitted electrons / incident electron. One should remember that SE emission produced by minimum ionizing particles in non-porous CsI in a non-vacuum environment has an efficiency of only a few per cent.

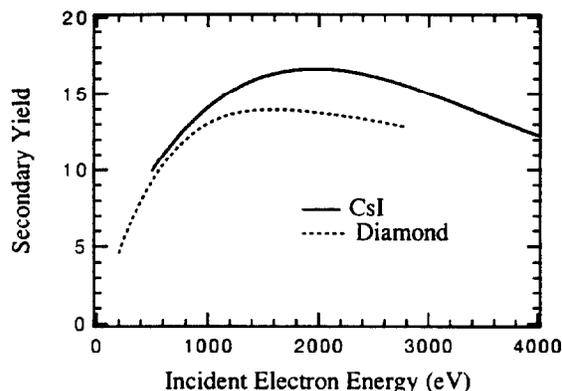


Fig. 3. Secondary yields as a function of incident electron energy for CsI [19] and a CVD diamond film [18]. Measurements are made with the incident electron striking the surface of the emitter.

The low work function of CsI (0.1 eV) and its long free electron range [11] suggested that it might be a suitable surface treatment for diamond films. Working with the NASA Lewis Research Center, and Case Western Reserve University, we attempted to demonstrate the validity of the idea. We found that when the electron beam struck the CsI-coated diamond surface, the coating dissociated and was pumped away. What was left was a treated diamond surface that was air stable (at least for short periods) and had significantly enhanced yield. Auger-electron spectroscopy showed Cs with very little iodine on the treated surface. The relative concentrations of Cs and C on the surfaces indicated that the Cs coating was very thin, approximately one monolayer. Diamonds that have been coated with Cs metal are not air stable and there has been a problem with the Cs metal adhering to the diamond surface. It appears that the cesiation of the diamond with CsI yields a significantly different result than conventional Cs coatings.

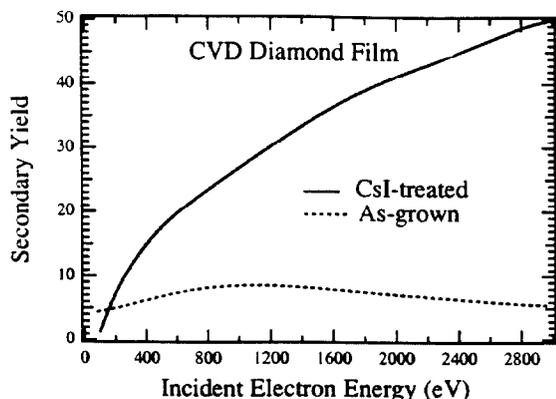


Fig. 4. Secondary yields as a function of incident electron energy for a CVD diamond films: as-grown and CsI-treated [20]. (See text)

Fig. 4 [20] shows the SE yield, measured at a pressure of 10^{-7} Torr, as a function of incident electron energy, of a diamond sample as-grown and after an initial 100 Å coating of CsI and treatment by electron bombardment. The as-grown diamond has a peak yield of about 10 electrons/incident electron at 1 keV. As the energy increases the yield decreases. This is due to the higher energy electrons depositing their energy deeper in the diamond. The yield of the CsI-treated diamond, after exposure to the electron beam, continued to increase with energy. The yield for 3 keV incident electrons is 50 electrons / incident electron. Since the yield does not turn over in the energy range studied, it is clear that the extracted electrons are coming from much deeper in the diamond than in the case of the untreated diamond.

A revealing way of presenting the data for the CsI-treated diamond in fig. 4 is shown in fig. 5. Here the fraction of the maximum possible number of electrons liberated in the diamond is plotted as a function of incident electron energy. The value of 13 eV/ electron-hole pair was used[14], though this is a very conservative value considering the low electric field in the diamond and high dE/dx (and thus high recombination) of incident electrons of such low energy. At about 300 eV the electron yield is 50% of the maximum possible number. Even at 3 keV the collected charge is over 20% of the maximum.

The time stability of the SE emission yield of the as-grown and CsI-treated diamond films are also remarkably different, as can be seen in fig. 6 [20].

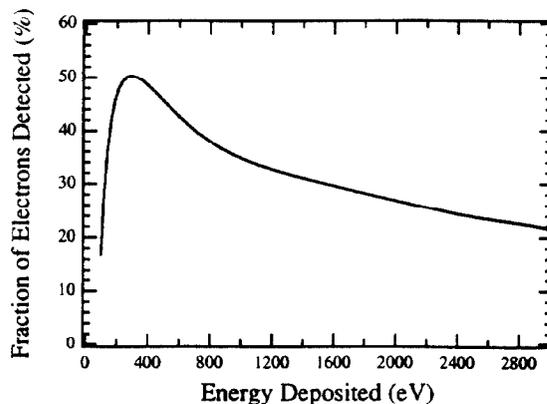


Fig. 5. Fraction of the maximum liberated electrons detected (assuming 13 eV/ion pair) as a function of deposited energy.

The response of the bare diamond is typical with the SE yield decreasing to about 30% of the initial yield in a few minutes and then remaining stable. The same diamond with the CsI treatment showed a rapid increase in SE yield followed by a slow increase thereafter. The measurements were made with an bombardment current of 15 mA/cm^2 .

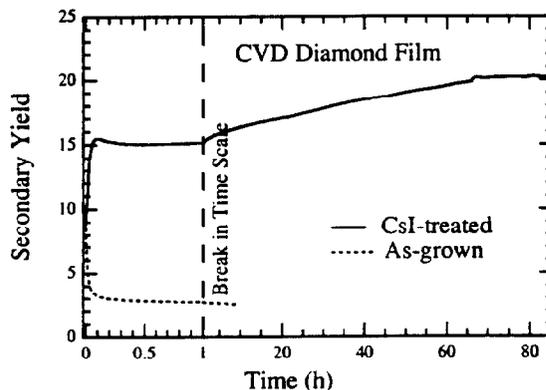


Fig. 6. Secondary yields as a function of time for a CVD diamond films: as-grown and CsI-treated [20]. (See text)

We have yet to study the SE emission of CsI-treated diamonds as we have done for CsI and KCl: i.e., using beta particles in a gas environment. This requires a device that will spray keV-energy electrons over an area of up to 5 cm in diameter. Such a device is under construction.

4. DISCUSSION

As was stated above, the key to making the low-pressure MSGC a viable technique for high-energy physics is the existence of an efficient and stable SE emitter that can be operated in a non-vacuum environment. From our work, it appears that CsI-activated diamond films offer the best chance of making such an emitter. If we are able to do in gas what has been done in vacuum (drift in the bulk and extract) one may be able to make surfaces that yield as many as 36 electrons per micron of diamond from a minimum-ionizing particle [14]. This would make possible low-pressure MSGCs with good single-strip efficiency, resolution, and timing; that are also insensitive to the angle of the incoming particles. A diamond SE emitter would also be very radiation hard [21]. Such a SE emitter may also yield compact time-of-flight detectors with excellent resolution that are able to work in a magnetic field.

ACKNOWLEDGMENTS

Work supported by the U.S. Department of Energy under contract No. DE-AC02-76CH03000.

REFERENCES

1. F. Angelini, et al., Nucl. Phys. B 23A (1991) 254.
2. F. Angelini, et al., Nucl. Instr. and Methods A315 (1992) 21.
3. RD-28. Collaboration, Development of the Micro-Strip Gas Chamber for Radiation Detection and Tracking at High Rates, CERN/DRDC/93-34, 1993.
4. F. D. v. d. Berg, et al., Nucl. Instr. and Meth. A349 (1994) 438-446.
5. D. F. Anderson, S. Kwan, and M. Salomon, Nucl. Instr. and Meth. A346 (1994) 102.
6. S. Kwan, et al., Test Beam Results of a Low-Pressure Micro-Strip Gas Chamber with a Secondary-Electron Emitter, IEEE Nuclear Science Symposium Norfolk, Virginia, 1994, vol. IEEE NS-42.
7. R. Chechik, et al., Nucl. Instr. and Meth. A342 (1994) 458.
8. A. Akkerman, et al., J. Appl. Phys. 72(11) (1992) 5429.
9. A. Buzulutskov, A. Breskin, and R. Chechik, Field Enhancement of the Photoelectric and Secondary Electron Emission from CsI, WIS-94/11/Feb.-PH, 1994.
10. A. Gibrekhterman, et al., The Spatial Characteristics of Electron-and Photon-Induced Secondary Electron Cascades in CsI, WIS-93/120/Dec.-PH, 1993.
11. A. Akkerman, et al., Low Energy Electron Transport in Alkali Halides, Preprint WIS-94/12/Feb.-PH, 1994.
12. L. S. Pan, et al., J. Appl. Phys. 73(6) (1993) 1.
13. L. S. Pan, et al., Diamond and Related Materials 2 (1993) 820.
14. M. Franklin, et al., Nucl. Instr. and Meth. A315 (1992) 39.
15. B. B. Pate, et al., J. Vac. Sci. Technol. 21(2) (1982) 364.
16. B. B. Pate, et al., Physica 117B & 118B (1983) 783.
17. J. v. d. Weide, and R. J. Nemanich, J. Vac. Sci. Technol. B10 (2) (1992) 1940.
18. T. L. Bekker, et al., IEEE IEDM Tech. Dig. (1992) 37.3.1-37.3.4.
19. I. M. Bronshtein, and B. S. Fraiman, Secondary-Electron Emission, Nauka, Moscow, 1969, vol. pp. 283-293.
20. G. T. Mearini, et al., Stable Secondary Electron Emission from CVD Diamond Films Coated with Alkali-Halides, NASA LeRC Cont. no. 100, 1994.
21. S. Han, et al., Nucl. Instr. and Meth. B80/81 (1993) 1446.