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ABSTRACT

High-purity germanium charged particle telescopes, consisting of detectors with ultra-thin (~1000 Å) ion implanted p^+- and n^+-contacts and capable of stopping up to 200 MeV protons have been developed. Fixed and variable detector configurations which accomodate user needs are described. A spectrum from a ^{28}Si (p, p´) ^{28}Si scattering experiment demonstrates the performance of such telescopes.

INTRODUCTION

High resolution spectroscopy of long-range particles (e.g., 200 MeV protons), a field of growing interest with the availability of suitable accelerators such as LAMPF, TRIUMF, and several others, represents a serious challenge to experimental physics. Magnetic spectrometers always have relatively low efficiencies, and in this energy range, become extremely expensive. This problem has led to recent studies using semiconductor detector telescopes. These telescopes consist of stacks of several planar detectors where the total thickness is great enough to stop the particles of interest. Since the density of germanium is about 2.5 times that of silicon, and because detector technology places a practical limit of about 0.5 cm on the thickness of (lithium-drifted) silicon detectors, telescopes of germanium detectors appear to be more suitable for this energy range. The difficulties in handling several lithium-drifted germanium detectors [Ge(Li)] at room

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temperature make them unsuitable for a telescope application. However, the development of high-purity germanium has allowed our group to produce germanium detector telescopes which have already been used in a number of experiments.[1,2]

The detectors in these early telescopes were fabricated with metal Schottky barriers acting as the p^+-contact and thin lithium-diffused layers ($\gtrsim 10\ \mu m$) as the n^+-contact. The n^+-contact dead layer between detectors is clearly undesirable. The dead layer becomes intolerable when it thickens during the annealing cycle required to recover such detectors from the radiation damage that accompanies charged particle experiments. Consequently, the practical utility of high-purity germanium detector telescopes depends on the realization of very thin n^+-contacts which do not thicken significantly when a detector is subjected to prolonged annealing (e.g., several hours at 150°C or several days at 100°C).

DEVELOPMENT OF AN ULTRA-THIN WINDOW GERMANIUM DETECTOR TELESCOPE

It has been demonstrated that ion-implantation of phosphorous in high-purity germanium can be used to produce an n^+-contact which is extremely thin (~ 1000 Å) and remains so upon annealing.[3,4] A device with this type of contact can not only be considered essentially "windowless" but also treated for radiation damage without thickening the dead layer. The maximum electric field at these contacts before the onset of substantial carrier injection is ~2000 V/cm. Such a field limit is several times less than the maximum for a lithium diffused contact but still quite adequate for detector operation.

Using ion-implantation, ultra-thin window germanium detectors have been developed for use in charged-particle telescopes. The first reported telescope of this type utilized a pair of 3 mm thick devices, each with an active area of 3 cm.[2,3] We have produced ultra-thin window detectors with a maximum thickness of 1.5 cm and a maximum active area of ~11 cm^2. These large volume devices have been made possible by:

1) Using high-purity n-type germanium so that depletion begins from the p^+-contact. In this way, the lowest electric field is at the n^+-contact, thus allowing one to apply bias beyond depletion without exceeding the 2000 V/cm limit for the phosphorous contact.

2) Developing improved fabrication procedures, the details of which are contained in the Appendix.

To meet the varying needs of users, two types of ultra-thin window germanium telescopes have been constructed: fixed configuration and variable configuration. A fixed configuration telescope is one in which the detectors are arranged in a fixed geometry. The advantage of such an arrangement is that all the devices can be kept in a dedicated vacuum chamber which is continuously cooled to liquid nitrogen temperature. Such a clean, stable environment helps to avoid problems in detector operation due to surface contamination.

Variable configurations obviously provide more experimental flexibility. Depending on the particular experiment, detectors in separate mounts can be added, taken away or rearranged as silicon detector telescopes have been used for years at lower energies. As with fixed geometry telescopes, a housing must be provided so the germanium detectors will be in high vacuum at their operating temperature (~77K). In anticipation of possible surface contamination from frequent handling and thermal cycling, the devices used in these telescopes have been treated by a surface passivation process as described by Dinger.5)

RESULTS AND SUMMARY

Table 1 lists the ultra-thin window detector telescopes fabricated by our group which are currently in use at various facilities. An example of a fixed detector telescope is shown in Figure 1--an eight-detector instrument which will stop 200 MeV protons. It is being used at the Los Alamos Meson Facility (LAMPF). Average operating bias for the seven ultra-thin window germanium detectors is ~2000 V, which is at least 500 V past the depletion voltage for any detector in the telescope.

Figure 2 demonstrates the application of a two-detector variable configuration telescope at the Indiana University Cyclotron facility. A ^{28}Si (p, p′) ^{28}Si experiment produced 115 MeV protons which were stopped by two 15 mm thick ultra-thin window germanium detectors. The proton peaks have a FWHM of 180 KeV. This resolution has been fully accounted for by summing the contributions of beam spread, reaction kinematics, detector statistics and electronic noise for the particular electronics in this experiment. The contribution of the detector to resolution cannot be deduced from this experiment but it is clearly quite small.

We have shown that techniques developed for producing ultra-thin blocking contacts on high-purity germanium by ion implantation can be successfully applied to the construction of charged particle telescopes. These telescopes are complementary to the conventional magnetic particle spectrometers which are quite large, very expensive, and only cover a limited energy range at one time. The germanium detector telescope is much smaller, considerably less expensive and records events simultaneously over a large energy range. Early results indicate this type of telescope is useful for particles whose ranges are equivalent to protons up to 200 MeV and that the energy resolution in such experiments may often be limited by factors other than the detectors. In addition, a pair of telescopes can be employed in two-arm coincidence experiments, an application which is difficult to consider with other types of spectrometers. It is apparent that ultra-thin window germanium detector telescopes offer new tools for long-range particle spectroscopy.

ACKNOWLEDGEMENTS

We sincerely thank D. Friesel and P. Singh of the Indiana University Cyclotron facility for furnishing the data shown in Figure 2. In addition, we wish to acknowledge the assistance of Richard Cordi, of our group, in fabricating the detectors, and Don Rogers of the Electronics Research Laboratory, University of California, Berkeley, for making available the ion implantation equipment.

Finally, we wish to thank Fred Goulding for his continued support and Richard Pehl for stimulating this work and for acting as liason with the experimental groups using these detector systems.

APPENDIX

Contact Fabrication

As reported earlier$^{4)}$, a non-injecting n^+-contact can be produced by implanting 25 KeV ^{31}P into a liquid nitrogen cooled germanium sample. The details of the implantation procedure have been changed from the earlier publication in a few areas:

1) Immediately after implantation, the implantation region is protected by red vinyl tape and the sides of the device are etched to remove contaminants deposited during the implantation process. Unless this is done, unwanted impurities diffuse in during the annealing cycle to create a charge-trapping region near the periphery of the device. The usual etching procedure is first to spray etch with a mixture of HNO_3: HF: Red fuming HNO_3 [7:2:1], rinse with distilled deionized water (DDW), spray etch with DDW: H_2O_2: HCl [5:1:1], rinse with DDW and blow dry. When the tape is removed from the phosphorous implanted surface, trichlorethelene and distilled methanol are used to dissolve any residual glue.

2) A longer "pre-anneal" of 24 to 60 hours at 150°C is given to repair the damage created beyond the end of the range of the implanted phosphorous. From this nearly perfect substrate, the amorphous implanted region can be regrown by increasing the temperature at a rate of 20°C/20 min. to a maximum of 330°C.

3) Following the annealing, the desired area of the ultra-thin n^+ contact is masked by a Teflon* disk and a 1 mm wide lithium "ring" is evaporated and diffused at the circumference of the contact. It has been found that finished detectors exhibit high leakage currents at low bias in the absence of an n^+-lithium ring.

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*Reference to a company name or product name does not imply approval or recommendation of the product by the University of California or the United States Department of Energy to the exclusion of others that may be suitable.

4) To eliminate possible problems with spreading resistance, a 200 Å layer of Pd is evaporated over the n^+-contact.

5) A p^+-contact is now routinely produced using $^{11}B^+$-implantation in lieu of a Schottky barrier. A dose of 10^{14} ions cm^{-2} at an energy of 25 KeV into a room temperature germanium substrate produces a blocking p-type contact without annealing.6) With careful handling and pre-cleaning as described for the ^{31}P implantation, the yield of non-injecting p^+-contacts has been close to 100%.

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FACILITY/USER	TYPE OF TELESCOPE	NUMBER OF DETECTORS	DETECTOR ACTIVE AREA	DETECTOR THICKNESS
1) University of Virginia and Los Alamos Meson Facility (Klaus Ziock)	Fixed	7 Germanium 1 Si(Li) ΔE	Min. 8.6 cm^2 to Max. 11.3 cm^2	Avg. 12 mm
2) University of Virginia and Los Alamos Meson Facility (Klaus Ziock)	Fixed	3 Germanium 1 Si(Li) ΔE	Avg. 8.6 cm^2	Avg. 12 mm
3) Indiana University Cyclotron Facility (Dennis Friesel)	Variable	4 Germanium (11 Ge planned)	Avg. 4.9 cm^2	2- 15 mm 2- 10 mm
4) University of Maryland Cyclotron Laboratory (Philip Roos)	Variable	2 Germanium	Avg. 3.8 cm^2	Avg. 13 mm

TABLE 1.

FIGURE CAPTIONS

Figure 1. An eight-detector fixed position telescope [7 high-purity germanium and 1 Si(Li)] is shown. The telescope is one of two being used in coincidence experiments at LAMPF. Each germanium device has a ^{31}P-implanted n^+-contact. Total germanium thickness is 83 mm.

Figure 2. Energy spectrum for the scattering of 115 MeV protons from a 10 mg/cm^2 ^{28}Si target. The spectrum was observed with a detector telescope consisting of two 15 mm thick high-purity germanium detectors with ultra-thin contacts. The proton beam, accelerated in the Indiana University Cyclotron, had a resolution of about 110 KeV.

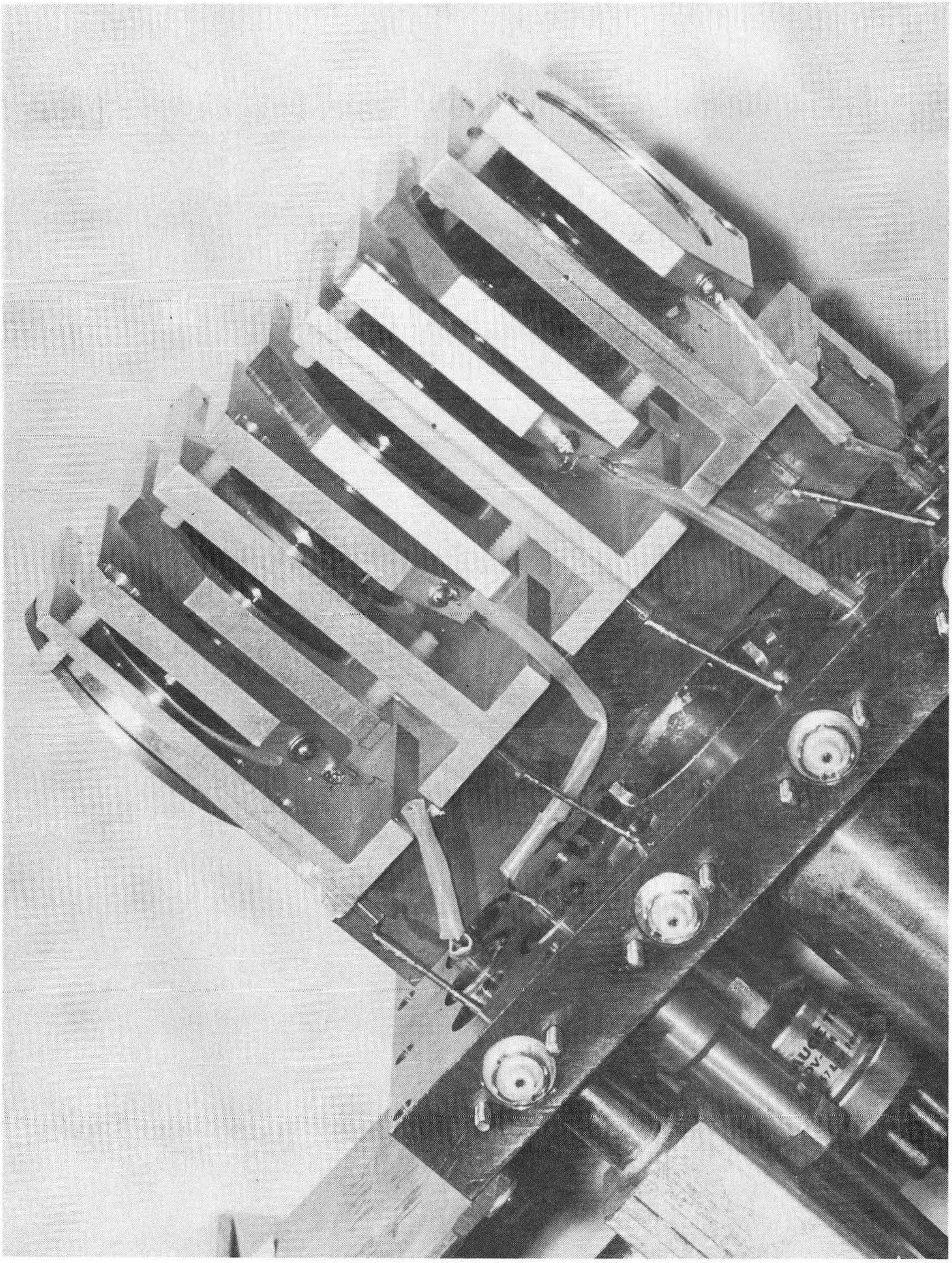

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Fig. 1

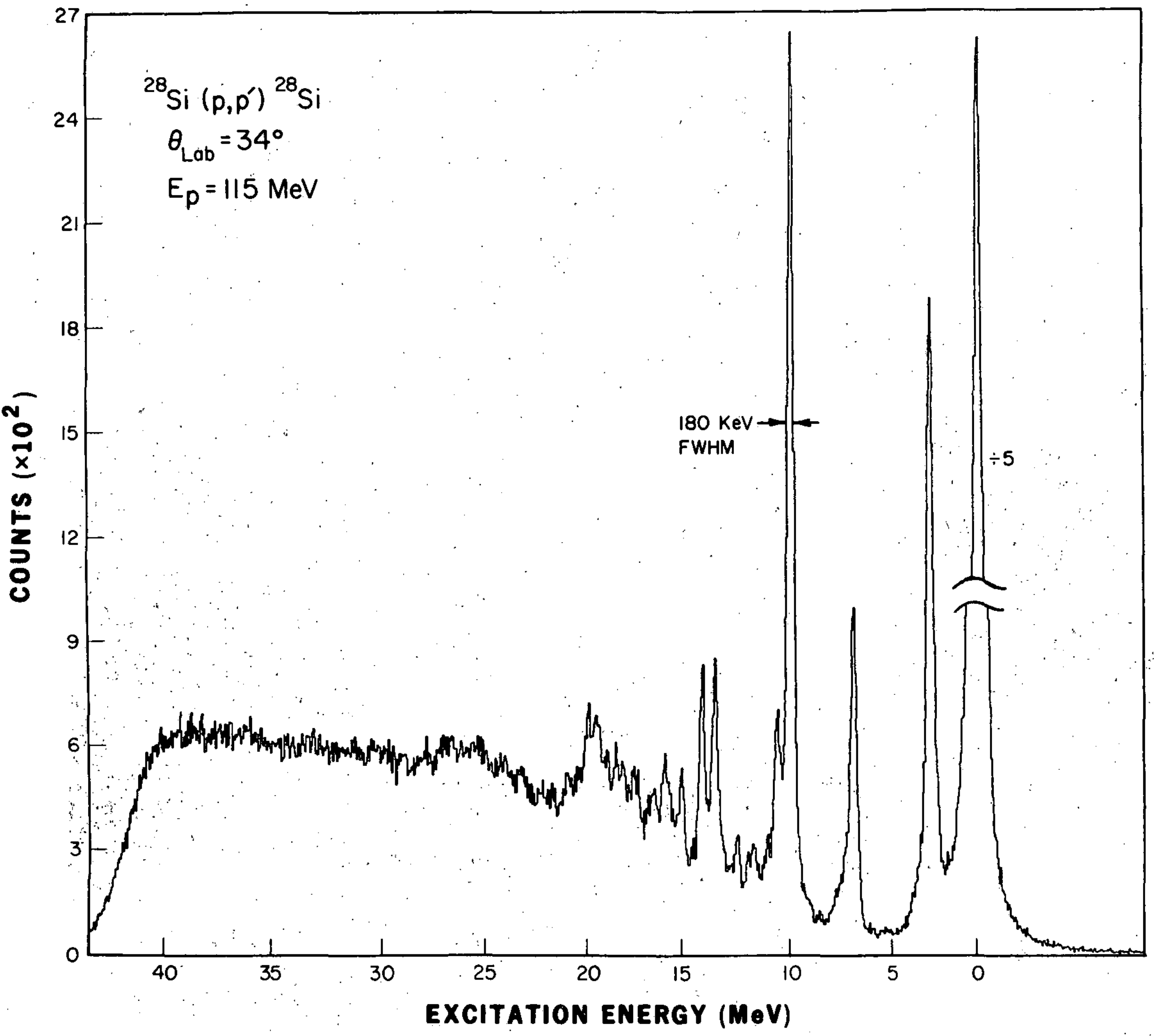

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Fig. 2

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