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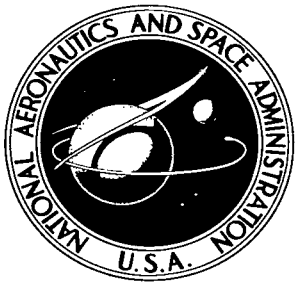

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MANUFACTURE OF LITHIUM-DRIFTED SILICON SURFACE-BARRIER SEMICONDUCTOR COUNTERS

by Norton Baron and Gerald A. Kaminski

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1966

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SUMMARY

The source material for manufacturing counters should be monocrystalline silicon, which closely meets the specifications detailed herein. The procedures involve a minimum of sophisticated technology. Counter size manufactured by these procedures varies in compensated depth from 1000 to 7000 microns and in diameter from 1.0 to 1.5 centimeters. At present, there is no indication that greater lithium-compensated depths cannot be achieved. The resolution of these counters, cooled to dry-ice temperature, is typically between 15 and 25 keV for 6-MeV alpha particles. The typical response of these detectors to monoenergetic charged particles is shown graphically. There is no high-energy tail, and the low-energy tail is not severe. It should be recognized that accelerator scattering systems capable of 10-keV resolution work, when magnetic analysis is used for the reaction product particles, could readily achieve better than 25 keV overall resolution by using these counters.

INTRODUCTION

Procedures for the manufacture of lithium-drifted silicon surface-barrier semiconductor counters are presented. Typical diameters of these counters vary from 1.0 to 1.5 centimeters, and the lithium-compensated depths vary from 1000 to 7000 microns. The diameter is limited because it is difficult to grow a large-diameter silicon crystal that has the required low dislocation density at its outer edge. At present, there is no indication that much greater compensated depths cannot be achieved. Resolution of these counters at dry-ice temperature is typically 10 keV for beta particles and 15 to 25 keV for 6-MeV alpha particles. At room temperature, the resolution is typically 15 keV for beta particles and 25 to 50 keV for 6-MeV alpha particles.

The manufacturing process can be divided into the following five major operations,

after each of which the wafer can be set aside indefinitely for future completion:

(1) Crystal specification, evaluation, and appropriate starting wafer thickness
(2) Diffusion of lithium into silicon wafer
(3) Determination of diffused-wafer diode characteristics and subsequent drift of lithium
(4) Final processing of lithium-compensated silicon wafer
(5) Mounting of finished counter

Generally, manufacturing procedures that necessitated a minimum of sophisticated technology and specialized equipment were adopted, as evidenced by the following description of the manufacturing process. Electronic grade chemicals are used throughout the fabrication process. Either absolute ethanol or methanol is suitable where alcohol is specified. The acid concentrations are 70 percent nitric acid, 48 percent hydrofluoric acid, and glacial acetic acid.

CRYSTAL SPECIFICATION

High quality silicon material must be used for manufacturing semiconductor counters that have characteristics of good resolution, deep compensation, and large cross-sectional area. The source material is ordered to the following specifications:

(1) Monocrystalline silicon
(2) Float-zone refined to residual boron content
(3) Lineage free
(4) Dislocation density less than 10 000 per square centimeter
(5) Diameter approximately 2 centimeters
(6) Wafers cut along (111) plane
(7) P-type
(8) Minimum lifetime, 500 microseconds
(9) Resistivity approximately 750 ohm-centimeter

The silicon material can be obtained in the form of a rod, or it can be sliced to the desired wafer thickness and precision lapped by the vendor prior to shipment.

CRYSTAL EVALUATION

Preparation of Surfaces

Determination of the crystal dislocation density was made for only one wafer from a crystal. It was assumed that the dislocation density of a wafer sliced from a crystal was typical of the whole crystal. The surfaces of the wafer were lapped to a smooth finish with no scratches visually evident. Lapping can be done manually by using plate glass as the lapping surface and aluminum oxide as the lapping compound. As a precaution against contamination of the wafer surfaces, disposable plastic gloves were worn when-

ever, during manufacture, it was necessary to handle the wafer. Initially, the wafer was lapped with 1200-mesh compound. After lapping, it was washed and scrubbed (with a cotton swab) under cold, running, triple-distilled, de-ionized water. Following the 1200-mesh lap and subsequent scrubbing, the procedure was repeated by using 3200-mesh lapping compound. The wafer was then soaked in nitric acid for several minutes as a final clean-up precaution, scrubbed under running de-ionized water, and dried by blowing high-purity dry nitrogen gas over the wafer while holding it in a pair of clean stainless-steel tweezers.

Polish Etching Wafer Surfaces

The wafer was placed in a polyethylene beaker containing CP-4A etchant[1] for $2\frac{1}{2}$ minutes at room temperature in order to obtain a polished finish on the surfaces. The etching solution was agitated by a magnetic stirrer. At the end of $2\frac{1}{2}$ minutes, the etchant was quenched by running de-ionized water. The wafer was removed from the quenched etchant with the aid of stainless-steel tweezers, while it was held simultaneously in a stream of running de-ionized water for several minutes to ensure that all the etchant had been displaced by the water.

Etching Procedure for Determination of Dislocation Density

After the polishing procedure, the wafer was placed in a polyethylene beaker that contained an etchant[2] sufficient in quantity to immerse the wafer. After approximately 1 hour, etch pits at the positions of crystal dislocations became visible that were observable with a low-power microscope.

A wafer etched in the manner just described is shown in figure 1. The dislocation density at the outer edge was typically larger than at the wafer center. The center portion dislocation density should have been less than 10 000 etch pits per square centimeter. An enlargement of the etch pits within a 1- by 0.8-millimeter area at the wafer edge is shown in figure 2. In subsequent operations, the poorer material at the outer edge of the wafer was removed. If, except for the outer edge, the dislocation density of the wafer was sufficiently small, then the manufacture of counters with this wafer and subsequent wafers cut from the same crystal can proceed. Otherwise, the entire crystal will be discarded.

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[1]Five parts HNO_3: three parts HF: three parts glacial acetic acid.

[2]Etchant: 120 parts acetic acid, 36 parts nitric acid, 12 parts hydrofluoric acid, and 1 part sodium nitrite solution composed of 1.5 grams of sodium nitrite in 6 milliliters of de-ionized water.

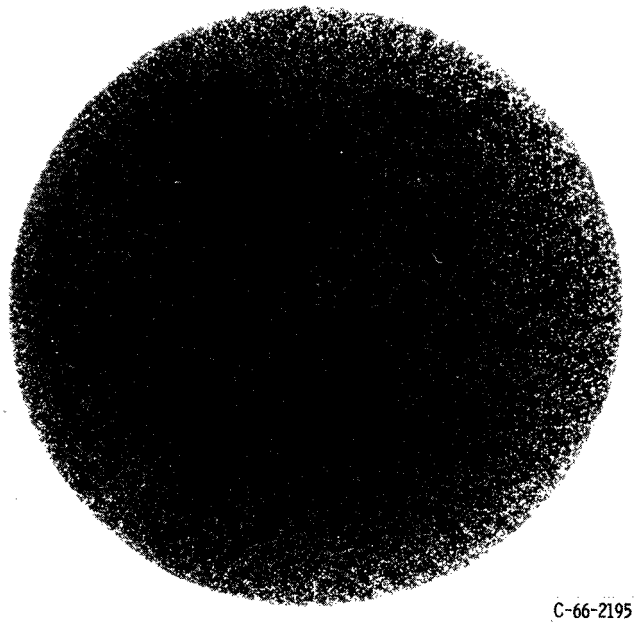

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Figure 1. - Etched silicon wafer showing large dislocation density at outer edge. Wafer diameter, 2.1 centimeters.

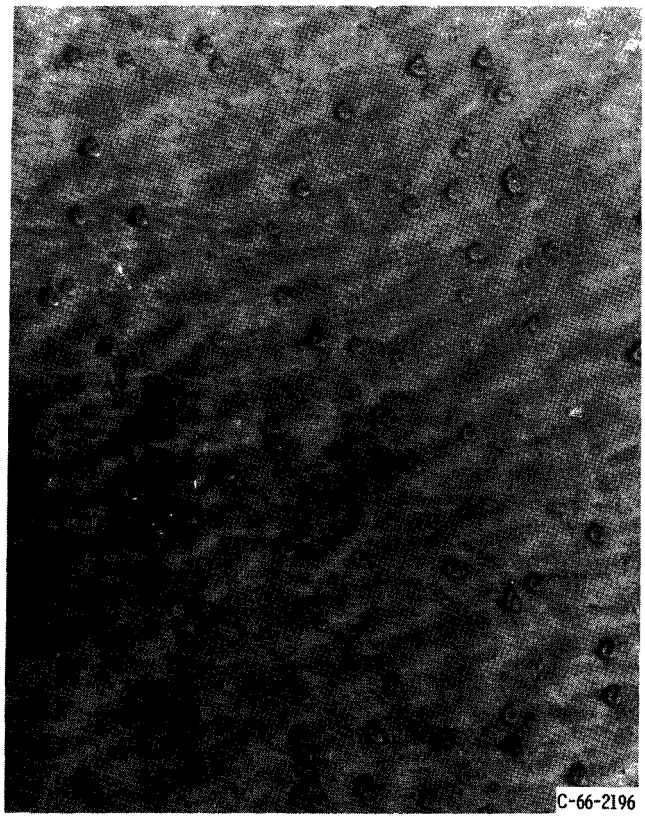

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Figure 2. - Enlargement of 1-by 0.8-millimeter area at wafer edge showing etch pits.

APPROPRIATE STARTING WAFER THICKNESS

The useful thickness of a completed counter is approximately 1000 microns less than the initial thickness of the wafer because the diffused lithium junction depth is approximately one-tenth the wafer thickness and approximately 500 microns are lapped and etched away during final counter processing. Thus, for manufacturing a counter, the wafer thickness should be chosen accordingly. This extra thickness of the wafer chosen for fabrication can be reduced somewhat from the preceding dimensions depending on the skill and experience acquired in manufacture.

DIFFUSION OF LITHIUM INTO SILICON WAFER

Evaporation and Diffusion Procedure

After the wafer was prepared as described in Preparation of Surfaces, it was placed inside a bell jar in which an oil-free vacuum of about 2×10^{-6} millimeter of mercury was obtained. The evaporation and diffusion assembly is shown in figure 3. Prior to evacuation of the bell jar, a small amount of lithium (cleaned by soaking and scrubbing with trichlorethylene) was inserted into an evaporation basket formed by a coil of tungsten wire. A boron nitride mask was placed over the wafer, situated on a slab of carbon beneath the basket of lithium, in order to allow lithium evaporation only on the low dislocation density region of the wafer. A secondary mask was placed in the bell jar in order to keep as much of the evacuated chamber as possible free of evaporated lithium. A clip spring forced the boron nitride mask and silicon wafer against the carbon base. A thermocouple wire was placed between the silicon wafer and boron nitride mask and was held in place by pressure on the mask due to the clip spring.

After evacuation, the wafer was heated by the carbon strip on which it was placed. The temperature of the top surface, as measured by the thermocouple, was stabilized at 375° C. At that time, the lithium was evaporated onto the silicon wafer surface. Approximately 1 minute of diffusion at 375° C produced a junction depth (hereinafter referred to as diffusion depth) of 100 microns. The diffusion depths given in table I for given wafer thicknesses provide a sufficient quantity of lithium atoms to compensate the remainder of the wafer.

When the desired diffusion depth was obtained, the diffusion heat was turned off and the wafer was allowed to cool naturally in vacuum by radiation for approximately 1/2 hour. The wafer was then removed from the bell jar and placed in a small beaker of alcohol. The subsequent addition of several drops of water to the alcohol burned off the excess lithium. The wafer was then scrubbed under running de-ionized water and wiped

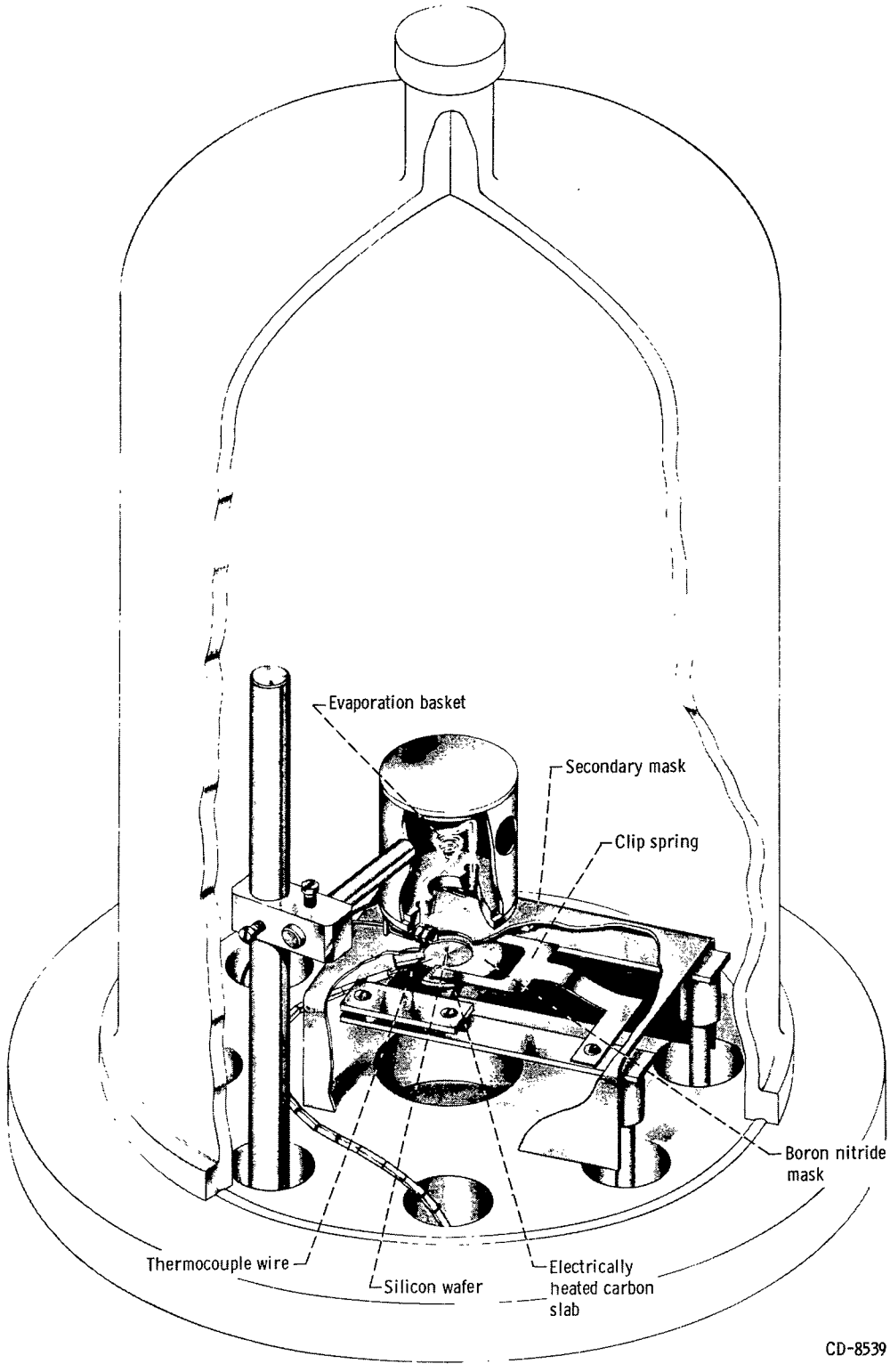

Figure 3. - Evaporation and diffusion assembly.

TABLE I. - DIFFUSION SCHEDULE

Wafer thickness, μ	Diffusion depth, μ	Diffusion time with a surface temperature of 375° C, min
2000	100	1
3000	200	2
4000	300	3
5000 to 6000	400	4
6000 to 8000	500	5

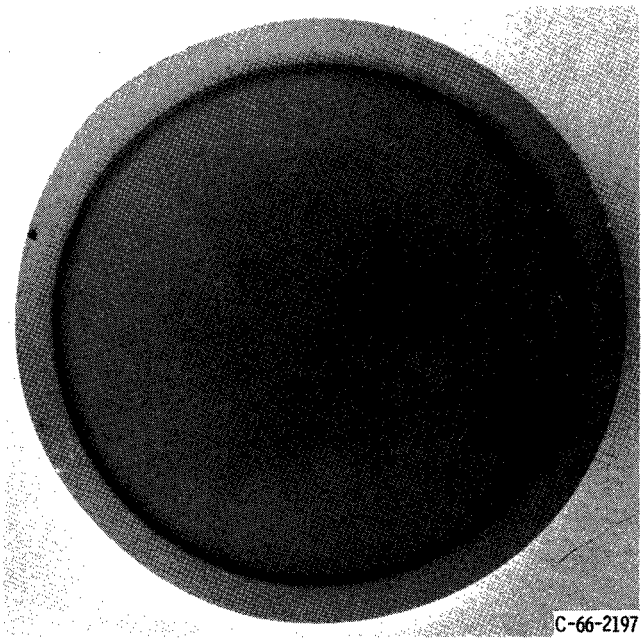

Figure 4. - Front surface of silicon after lithium diffusion. Wafer diameter, 2.1 centimeters.

dry with a soft tissue. In the remainder of this report, the lithium-rich surface of the wafer is called the front surface. The front surface of the wafer after it is removed from the bell jar is shown in figure 4.

Removal of Poor Quality Material at Outer Edge of Wafer

The edge of the wafer was sanded on a lapidary wheel by using 320-grit sandpaper, wetted with a constant flow of water for cooling, until the undiffused portion of the wafer was removed, thus eliminating the high-dislocation-density material at the edge. The apparatus for this operation is shown in figure 5. The front and back surfaces were then lightly lapped with 3200-mesh lapping compound, the surfaces and edge were scrubbed under running de-ionized water, and the wafer was dried by blowing nitrogen gas over it.

Determination of Diffusion Depth

In order to determine the depth and quality of the lithium diffusion, a stain etch[3] was performed by placing the wafer, front face down, into a polyethylene beaker con-

[3] 1000 Parts HF: 1 part HNO_3.

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Figure 5. - Lapidary wheel for sanding wafer edge.

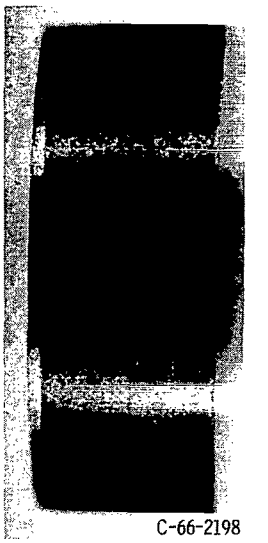

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Figure 6. - Stain etch on lithium-diffused silicon wafer. Wafer thickness, 6 millimeters; diffusion depth, 420 microns.

taining enough etchant to immerse the wafer completely. The lithium-doped silicon (strongly N-type material) was stained a light gray with respect to the P-type undiffused silicon, which was stained a dark gray or almost black. As the etchant acted on the silicon, small bubbles were observed to form at the wafer surfaces. Very often, the etchant will act on the silicon only after the stimulus of irradiation by a beam of incandescent light (supplied by a flashlight) and simultaneous slight agitation of the etchant. If the first attempt to stain etch was unsuccessful, the wafer surfaces were lapped lightly, the edge sanded lightly, and the stain etch again attempted by using the same etchant. The diffusion band must be sharp, even, and about the desired depth. The results of a stain etch on a lithium-diffused silicon wafer are shown in figure 6. At this point, the diffused wafer can be placed aside for drifting at a later date, if a satisfactory diffusion has been obtained.

DETERMINATION OF DIFFUSED-WAFER DIODE CHARACTERISTICS AND SUBSEQUENT DRIFT OF LITHIUM

Preparation of Diode

Clean-up of wafer edge. - The diffused wafer edge was carefully sanded on the lapidary wheel and made smooth as determined by visual inspection. As a final touchup to the edge, it was hand sanded under running de-ionized water with 600-grit sand paper.

Ohmic contacting front and back surfaces. - Both surfaces of the wafer were lapped lightly with 3200-mesh lapping compound, and the surfaces and edge were scrubbed under running de-ionized water. A pencil mark was made on the front surface for future easy identification. Then the wafer was inserted into a beaker of electroless gold-plating solution consisting of 40 milliliters of de-ionized water, 6 drops of hydrofluoric acid, and 8 drops of electroless gold-plating solution. The solution was gently heated just to boiling temperature. Within several minutes a rugged deposition of gold appeared on the wafer surfaces and edge, thereby providing good ohmic contact to the two surfaces.

Preparation of edge for polish etching. - In order to measure and subsequently utilize the wafer diode property resulting from the P-N junction, it was necessary to clean the wafer edge by removing any gold deposited there during the previous operation and then etching the edge to a polished finish. To protect the gold-coated surfaces of the wafer during this etching process, they were masked with wax. Masking was accomplished by placing the wafer on a microscope slide on a hot plate and by placing chips of wax on the exposed surface of the wafer. The heat from the hot plate caused the wax to flow. The wafer was turned over to expose the other side, and the process was repeated. Careful sliding of the wax-coated wafer off the glass slide left a good cover of wax on both surfaces. After allowing the wax to harden, any wax on the wafer edge was removed by peeling with a sharp blade, taking care not to damage the silicon. Any remaining wax on the edge was readily removed by a cotton swab wetted with trichlorethylene. The gold deposition on the edge was removed by light sanding on the lapidary wheel and a final touchup by hand-sanding under running de-ionized water.

Polish etching wafer edge. - The wafer was placed in a polyethylene beaker containing CP-4A etchant (see footnote 1) at room temperature, and a magnetic stirrer was used to agitate the etchant. After a $2\frac{1}{2}$-minute etch, the etchant was quenched with cold, running de-ionized water. The wafer was removed from the beaker of quenched etchant and kept under a stream of running de-ionized water for several minutes to displace all etchant thoroughly and then blown dry with nitrogen gas. This procedure was repeated for a second $2\frac{1}{2}$-minute etch of the edge. The wafer was inserted into a beaker of trichlorethylene to dissolve the wax covering the surfaces. After a thorough cleaning of the wafer with trichlorethylene and wiping with a soft tissue, the edge was thoroughly rubbed clean with a soft tissue wetted with alcohol and then blown dry with nitrogen gas.

Measuring wafer diode characteristic. - At this point, the diode properties of the wafer were measured by placing it in a light-tight enclosure (because of its photoelectric property) and applying reverse bias. If the diode was left to age for several hours under 400 volts reverse bias, it should conduct less than 5 microamperes of reverse current. The minimum diode characteristic acceptable in the laboratory is 5 microamperes reverse current under 100 volts reverse bias. If the diode property of the diffused wafer was unacceptable, the problem could usually be corrected by further sanding and etching

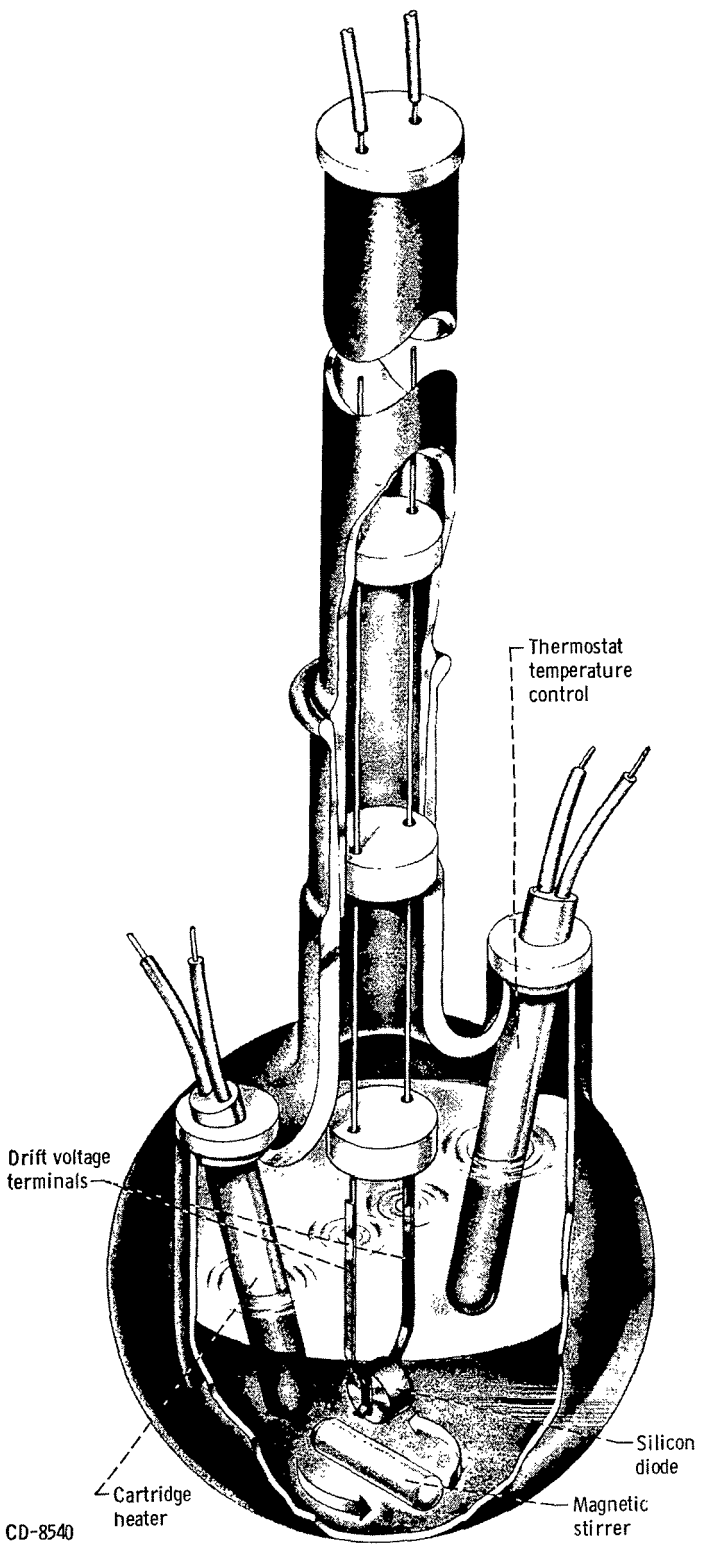

Figure 7. - Drifting apparatus.

of the wafer edge. (In such a situation, this unacceptable diode characteristic was attributed to crystal lineage at the outer edge of the wafer.) However, if after further sanding and etching of the wafer edge the diode characteristic was still unacceptable, the wafer was discarded.

Compensation of Silicon Wafer by Lithium Drifting

Description of drift procedure. - If the diode characteristic of the diffused-silicon wafer was satisfactory, the wafer was placed into the drifting apparatus (fig. 7). A beaker of fluorochemical is used as a heat sink for the diode during the drift. The fluorochemical, which was constantly stirred by a magnetic stirrer during the drift, was kept at a temperature of 120° C, and a reverse bias of 400 volts was applied to the wafer. The reverse current was constantly monitored during the drift. Generally, the reverse current was initially 0.5 milliampere (at 120° C) and increased to about 5 milliamperes when the drift was almost complete. Theoretical drift-depth predictions (ref. 1) were used to determine the time it takes to drift the lithium to within 100 microns of the back surface of the silicon wafer. At the predicted time, the wafer was removed from the 120° C fluorochemical bath,

while the reverse bias was maintained, until the wafer cooled to room temperature at which time the bias was removed from the wafer.

Inspection of compensation by stain-etching technique. - The back surface was hand lapped approximately 100 microns to remove the uncompensated P-type material, scrubbed under running de-ionized water, and blown dry with nitrogen gas. The wafer, back surface upward, was then placed in a polyethylene beaker that contained enough stain-etch solution (see footnote 3) to immerse the wafer. Because of a slight tendency for the lithium ions to penetrate further into the center of the wafer than at the outer edge, a light stain showing compensated material in the center but whose diameter is several millimeters less than the wafer diameter was observed after the first stain etch (see fig. 8). The back surface was then lapped approximately 100 microns, scrubbed and washed, and the stain etch was repeated until the lapping process had taken the back surface down to the intrinsic material to a diameter within at least 1 millimeter of that of the wafer (fig. 9).

The bowing of the lithium-drift profile was a result of a slightly higher temperature at the center of the wafer than at the edge, and, consequently, the lithium drift rate in the center region was slightly greater than at the edge. If the drift was allowed to proceed to within 100 microns of the back surface, no more than 300 microns is necessary to be lapped away from the back surface before the diameter of the compensated region, as shown by a stain etch, was well within 1 millimeter of the wafer diameter. The edge was then sanded on the lapidary wheel to remove the uncompensated P-type material caused by the aforementioned bowing.

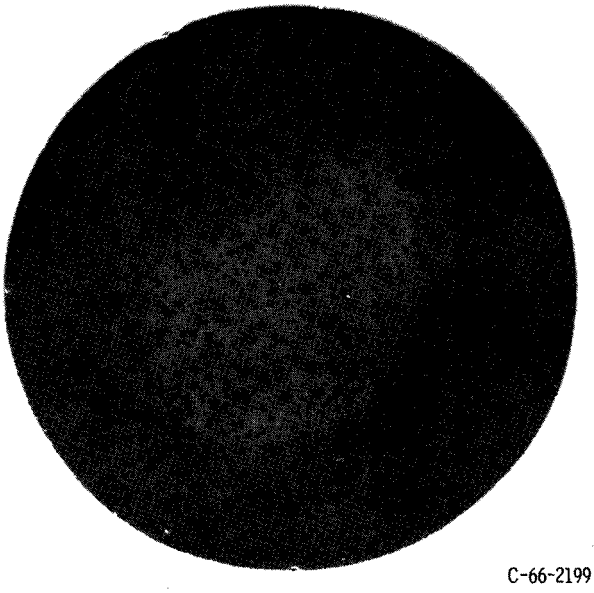

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Figure 8. - Stain-etched back surface of wafer drifted and subsequently lapped approximately 100 microns on back surface.

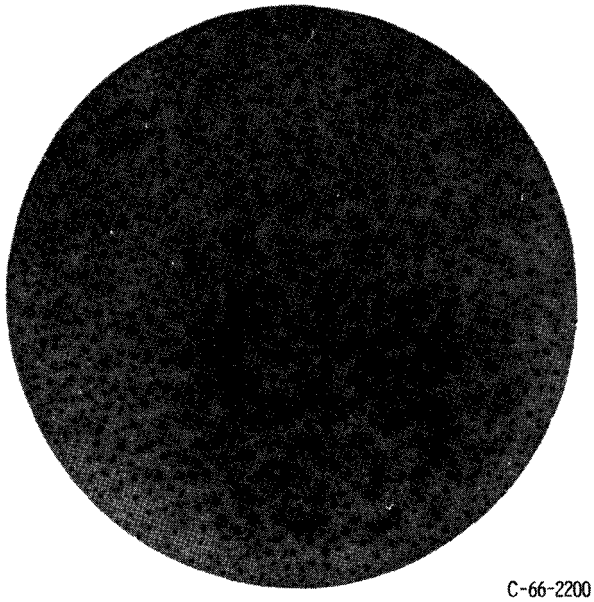

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Figure 9. - Stain-etched back surface of drifted wafer from which all unconpensated P-type material has been removed by lapping.

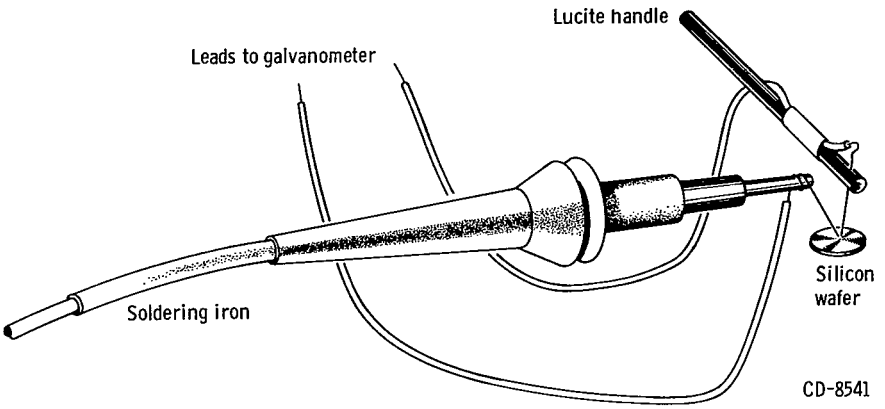


Figure 10. - Hot-probe arrangement.

Inspection of compensation by hot probing. - A further check on the quality of the compensation was made by a hot-probe measurement. Such a measurement involves the placement of two metallic pointed probes (such as pins) very close to one another on the surface to be examined. One of the pins was brought to an elevated temperature by wrapping it around the tip of a hot soldering iron. The electrical circuit was closed by connecting the heads of the pins to the input of a galvanometer (see fig. 10). The thermally generated carriers will result in a flow of current in one direction if the material spot being probed is P-type and in the opposite direction if the probed material spot is N-type. If the material is well compensated in the region probed by the pins, the galvanometer deflection will indicate the material is slightly N-type. A probe of an uncompensated wafer of P-type silicon can be compared with the lithium-diffused front surface of a wafer that is strongly N-type. The hot-probe measurements must be made on a lapped surface. Misleading results can be obtained if hot probing is performed on an etched surface. The hot-probe test affords a finer check than the stain etch on the quality of the compensation. If the hot probe showed that portions of the material were either too strongly compensated or uncompensated, lapping was continued until stain etching and hot probing showed that only the intrinsic material remained. At this point, the wafer could be set aside indefinitely.

FINAL PROCESSING OF LITHIUM-COMPENSATED SILICON WAFER

Electrical Contacting of Front Surface

The ohmic contact on the front surface was provided by the gold electroless deposition performed when the diffused wafer was prepared for drifting. If, at this point, the gold deposition had been loosened by stain etching, the wafer was lapped very lightly with 3200-mesh lapping compound, to remove the gold, was scrubbed under running de-

ionized water, and was then plated with a fresh gold cover by the previously described electroless gold-deposition technique. The head of a stainless-steel screw was attached to the center of the front surface with a small amount of silver paste that hardened overnight at 30° C. After the silver paste had hardened, wax was applied - in the manner previously described - to the front surface and allowed to cover the screw head as well as the total area of the front surface. The edge was lightly sanded on a lapidary wheel and touched up by hand sanding under running de-ionized water.

Polish Etching of Back Surface and Edge

The back surface was lapped with 3200-mesh lapping compound and scrubbed under running de-ionized water. The wafer was blown dry with nitrogen gas. A plastic pipette was cut at its tip and fitted snugly over the stainless-steel screw. The pipette thus provided a handle for holding the wafer during the final etching process (fig. 11). The wafer was held in a beaker of CP-4A etchant (see footnote 1), which was agitated by a magnetic stirrer, just deeply enough so that the liquid covered the screw head. After $2\frac{1}{2}$ minutes of etching, the etchant was quenched with running de-ionized water. The wafer was lifted out of the quenched etchant while being kept under a stream of running de-ionized water. It was thoroughly rinsed for about 2 minutes in the water stream before it was allowed to come into contact with air, at which time it was blown dry with nitrogen gas. At this point, extra precaution should be taken not to allow any foreign material to come into contact with the wafer. The etching procedure was repeated. Each $2\frac{1}{2}$-minute etch reduced the wafer thickness by about 150 microns.

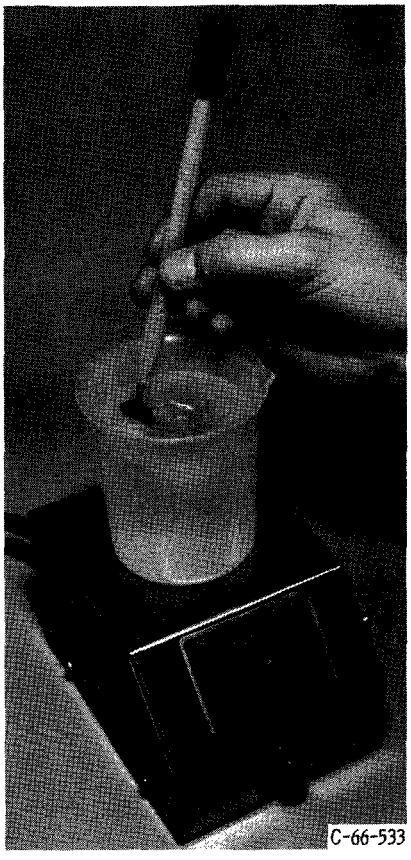


Figure 11. - Handling arrangement of wafer during final etching.

Ohmic Contacting of Back Surface

Following the second etching, the stainless-steel screw attached to the front surface of the wafer was inserted into a plastic holder, and the assembly was placed inside a bell jar. Positioned over the wafer was a tungsten evaporation basket in which a small amount of gold had been placed. A mask was inserted between the basket and the wafer in order to ensure that the subse-

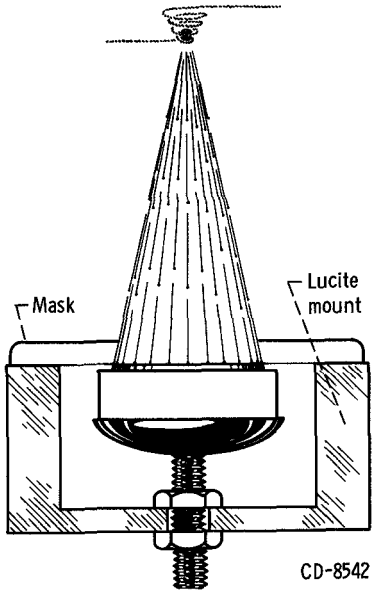


Figure 12. - Arrangement for gold evaporation onto back surface.

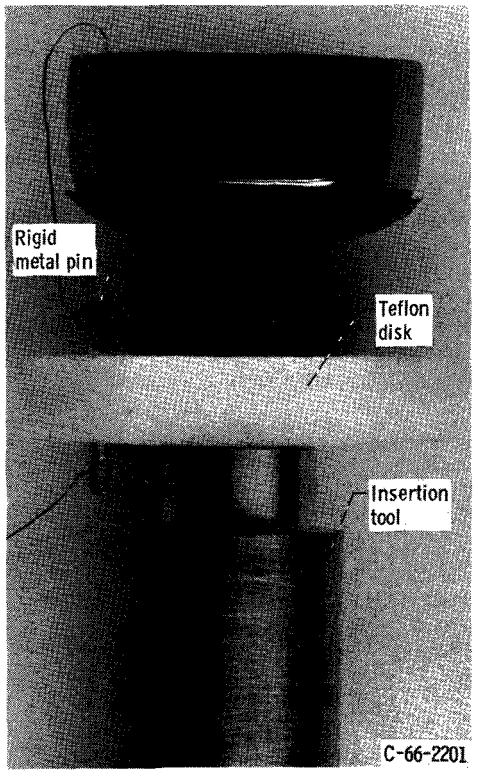


Figure 13. - Electrically contacted counter prior to its insertion into mount.

quent gold evaporation onto the back surface extended to within approximately 1/2 millimeter of the edge (fig. 12). On evacuation of the bell jar, a film of gold, approximately 100 angstroms thick, is then evaporated onto the wafer back surface.

Electrical Contacting of Back Surface

A Teflon disk (the diameter of which must fit the detector casing) was threaded over the stainless-steel screw with the aid of stainless-steel tweezers. A 1/4-inch-diameter brass rod, used as a temporary means of handling the wafer, was then threaded onto the stainless-steel screw. A rigid metal pin that extends through the Teflon disk has a length of gold wire attached to it by silver paste. The other end of the gold wire was shaped to touch the gold-coated back surface at a point close to the outer edge but wholly on the gold-coated surface. At that point, a small dot of a graphite-water colloidal dispersion was gently dabbed on with the aid of a glass rod and allowed to dry. The wire was placed on top of the dried dispersion and another small dot of it was applied on top of the wire. When the dispersion dried, the wire was bonded reasonably well to the gold-coated surface of the wafer. The electrically contacted wafer is shown in figure 13. The well-compensated wafer with electrical contacts on the front and back surfaces has become a lithium-drifted silicon semiconductor counter and can be inserted into its mount.

MOUNTING OF FINISHED COUNTER

The counter was slipped into the mount (fig. 14), which is a hollow tube of brass (11/16 in. o.d. and 5/8 in. i.d.) on the side of which is a BNC connector. The mount and the counter prior to assembly are

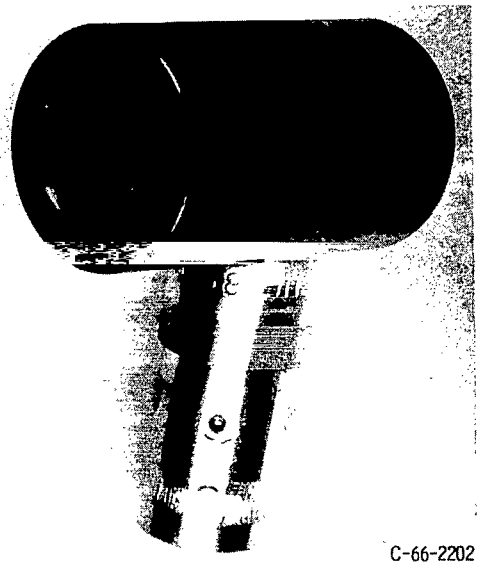


Figure 14. - Counter mount.

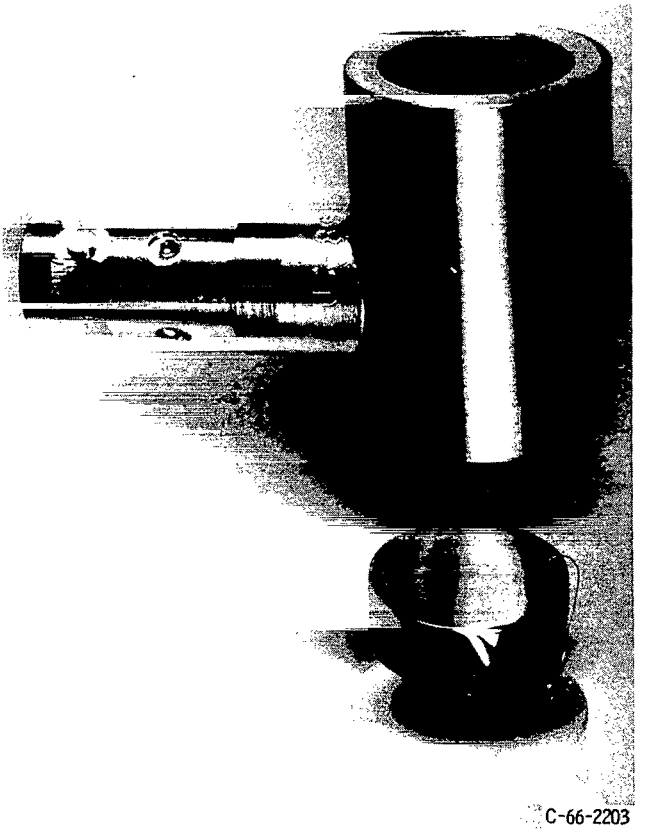
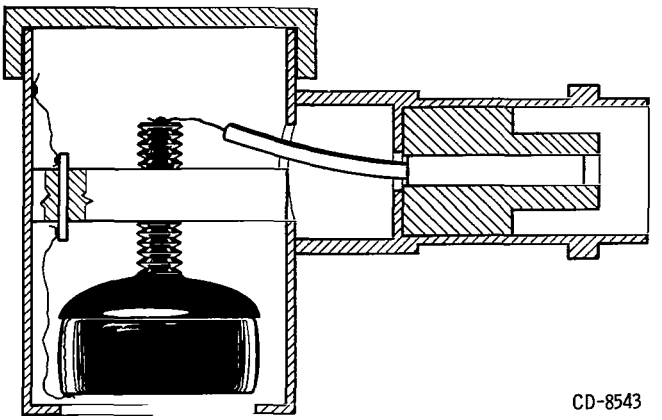
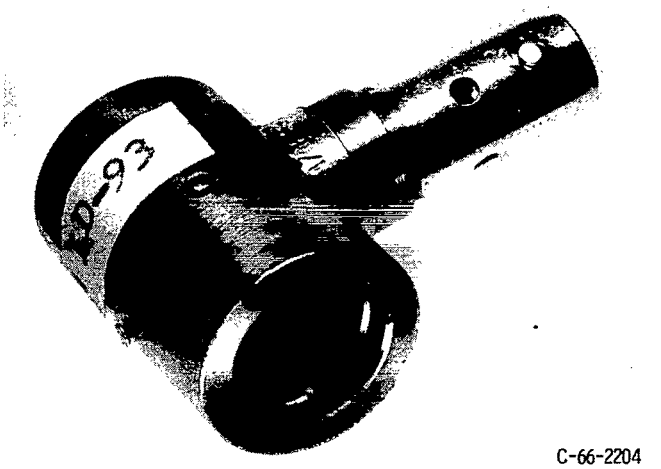


Figure 15. - Mount and counter prior to assembly.



(a) Schematic cross section.



(b) Overall view.

Figure 16. - Mounted counter.

shown in figure 15. The back surface of the counter was placed as near the front of the mount casing as possible. The Teflon disk, that should fit snugly, was held in place by several pins penetrating through the casing. The ground terminal was made from a pin penetrating the Teflon disk to the case by silver pasting a gold conducting wire into position. Similarly, the high-voltage terminal was completed by silver pasting a wire from the stainless-steel screw to the center conductor of the BNC connector. The back of the mount casing was covered by a brass plate held in position by a set screw. A schematic diagram of the mount assembly is shown in figure 16(a), and an overall view is shown in figure 16(b).

MEASUREMENT OF COUNTER RESOLUTION

Measurement of a counter's resolution by using monoenergetic beams of charged

particles is performed in an evacuated chamber, (fig. 17). Since the detector was cooled when its optimum resolution was measured, the backstreaming of pump oil into the chamber should be minimized, because it would then collect on the cooled counter surface. In such a situation, the oil deposition on the counter back face could cause a deterioration in its diode property by adversely affecting the P-type surface states, and possibly loosening the electrical contact with the graphite-water colloidal dispersion. The cleanest vacuum can be obtained with an adsorption pump, thus completely eliminating any possible oil contamination. A copper block, on which the detector was mounted, was cooled by circulating alcohol cooled by dry ice (fig. 18). The alcohol is circulated through a coil embedded in a thermoconductor on which a block of dry ice is placed. The alcohol is constantly recirculated by an electrical fuel pump. The temperature of the detector copper cooling block is quickly lowered to about -65° C, as determined by a thermocouple readout.

A mesothorium alpha source is placed in front of the counter in the test chamber shown in figure 17. The energies of the intense lines of this source are 6.05, 6.09, and 8.78 MeV. The mesothorium spectra (stored in a pulse-height analyzer) measured by

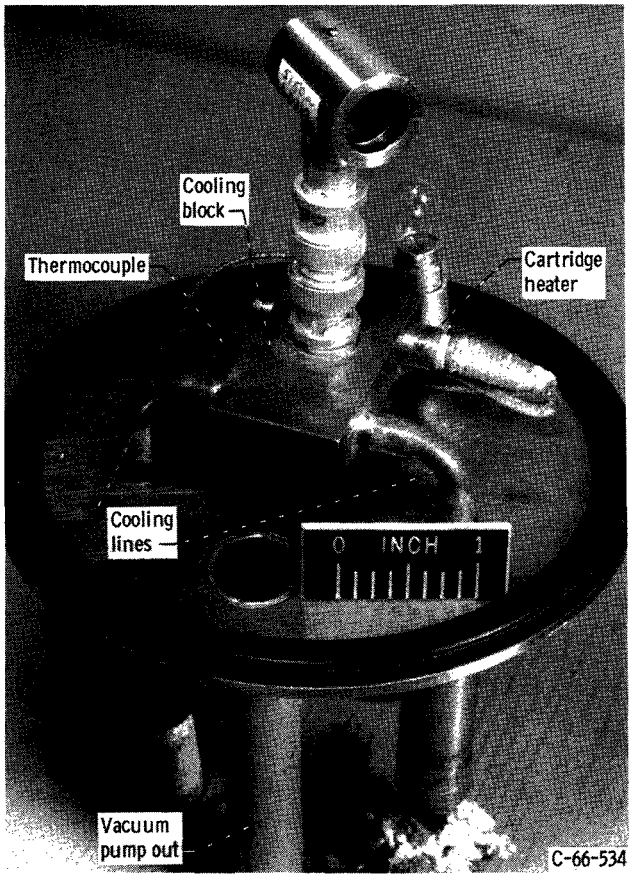


Figure 17. - Interior of test chamber used to measure resolution of counter.

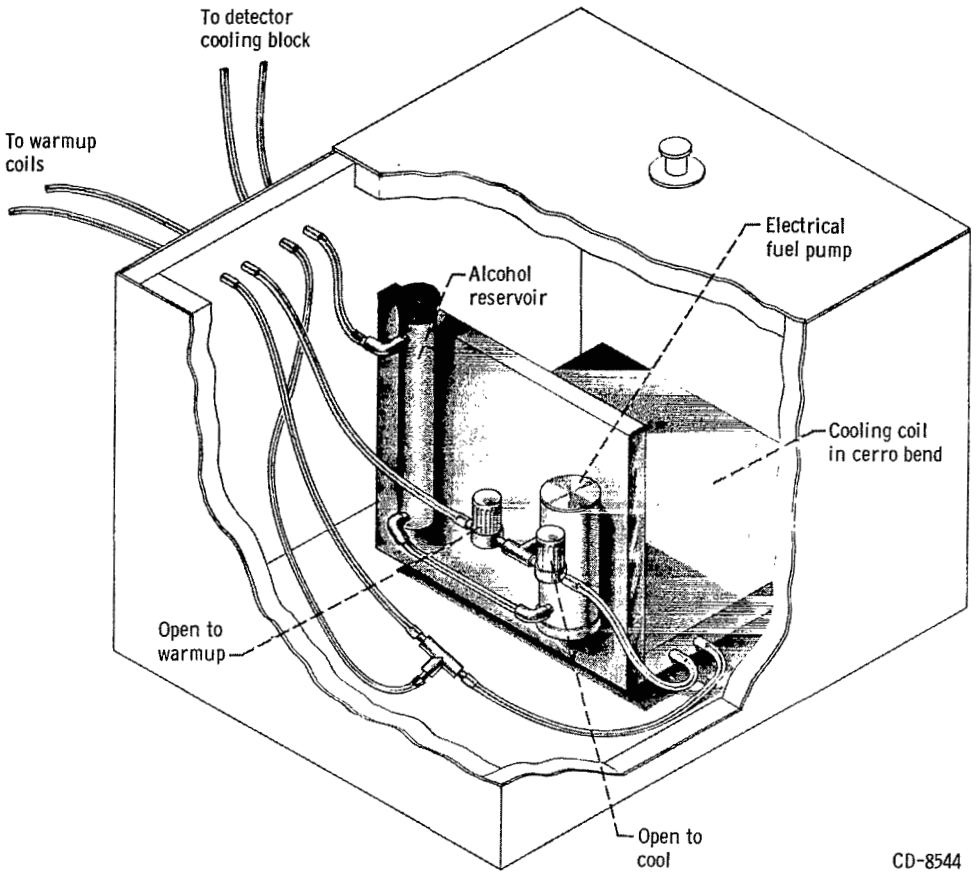
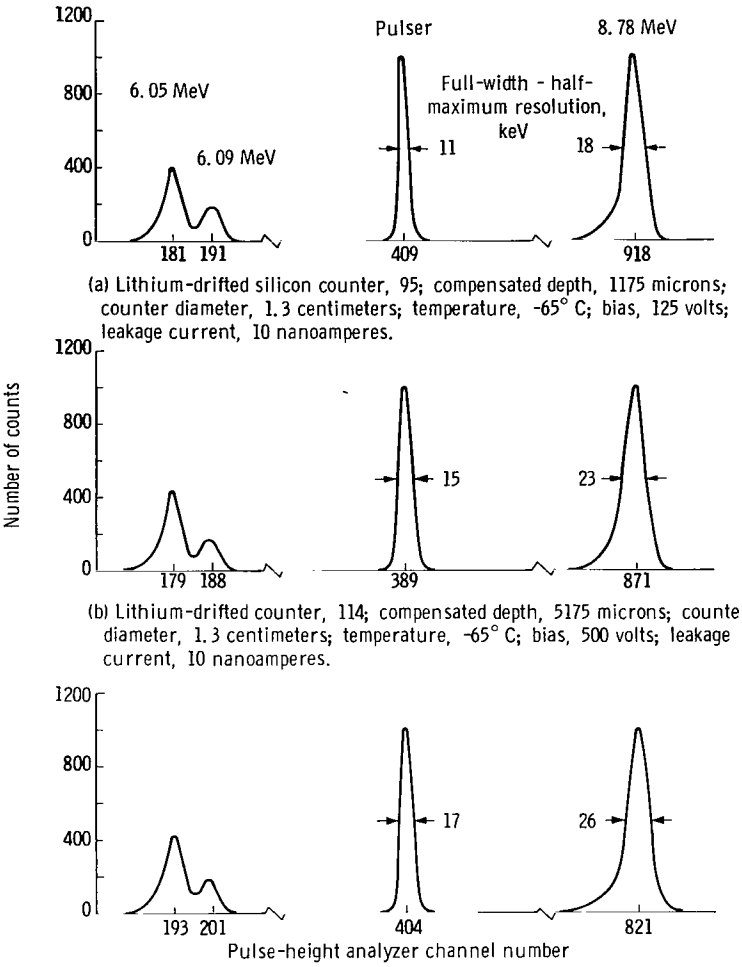


Figure 18. - Circulating alcohol cooling system.

lithium-drifted silicon counters of varying depths and a diameter of 1.3 centimeters and cooled to -65^{o} C are shown in figure 19. Typical leakage currents of a cooled counter at operating bias vary from 10 to 50 nanoamperes. The energy per channel is readily calculated and the full-width-half-maximum resolution is 18 to 26 keV. Note that clean separation occurs between the 6.05- and 6.09-MeV lines. There was no appreciable difference in the resolution when the counter was cooled to liquid-nitrogen temperature. These spectra are typical for counters fabricated in the manner discussed previously.



(a) Lithium-drifted silicon counter, 95; compensated depth, 1175 microns; counter diameter, 1.3 centimeters; temperature, -65° C; bias, 125 volts; leakage current, 10 nanoamperes.

(b) Lithium-drifted counter, 114; compensated depth, 5175 microns; counter diameter, 1.3 centimeters; temperature, -65° C; bias, 500 volts; leakage current, 10 nanoamperes.

(c) Lithium-drifted silicon counter, 92; compensated depth, 7100 microns; counter diameter, 1.3 centimeters; temperature, -65° C; bias, 900 volts; leakage current, 50 nanoamperes.

Figure 19. - Mesothorium alpha spectra measured by several cooled lithium drifted counters with different compensation depths.

STORAGE OF COUNTERS

Although absolute statements concerning the ability of counters to hold their high-resolution property are premature because of insufficient statistics, there is evidence of prolonged lifetime if they are stored under several hundred volts reverse bias in a light-tight enclosure. Most counters so stored have maintained their high resolution over an 8-month period. The several that did not were restored by removing the counters from their mounts and reprocessing them (p. 12). A more definite statement of the best long-term storage procedure must await the results of a carefully controlled experiment.

LITHIUM-DRIFTED SILICON COUNTERS USED IN TYPICAL ACCELERATOR SCATTERING EXPERIMENTS

The essentially nonanalyzed beam spread of 19-MeV protons accelerated in the University of Colorado cyclotron and detected by a lithium-drifted counter manufactured at Lewis by the method described in this report is shown in figure 20. These data were collected by Professor David Lind of the University of Colorado. The counter used in this measurement had a compensated depth of 2700 microns and a diameter of 1.3 centimeters. It was cooled to approximately -65° C by recirculating alcohol cooled by dry ice in the manner shown in figure 18 (p. 18). The measured 35 keV overall resolution of the detected particles is a result of the counter, electronics, and incident beam spread. It is interesting to note the relatively sharp cutoff on the high-energy side of the peak and the rather small low-energy tail. Comparison of figures 19 and 20 shows that the response of a counter to 19-MeV protons is essentially identical to that of 6-MeV alphas. In addition, the deteriorating effect on the overall resolution due to beam straggle when traversing the target foil is well illustrated in figure 20. On the basis of the

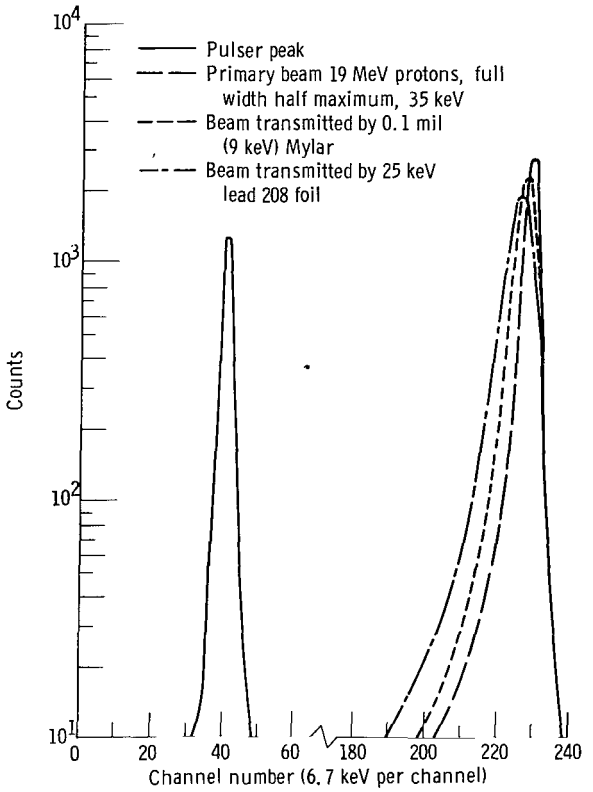
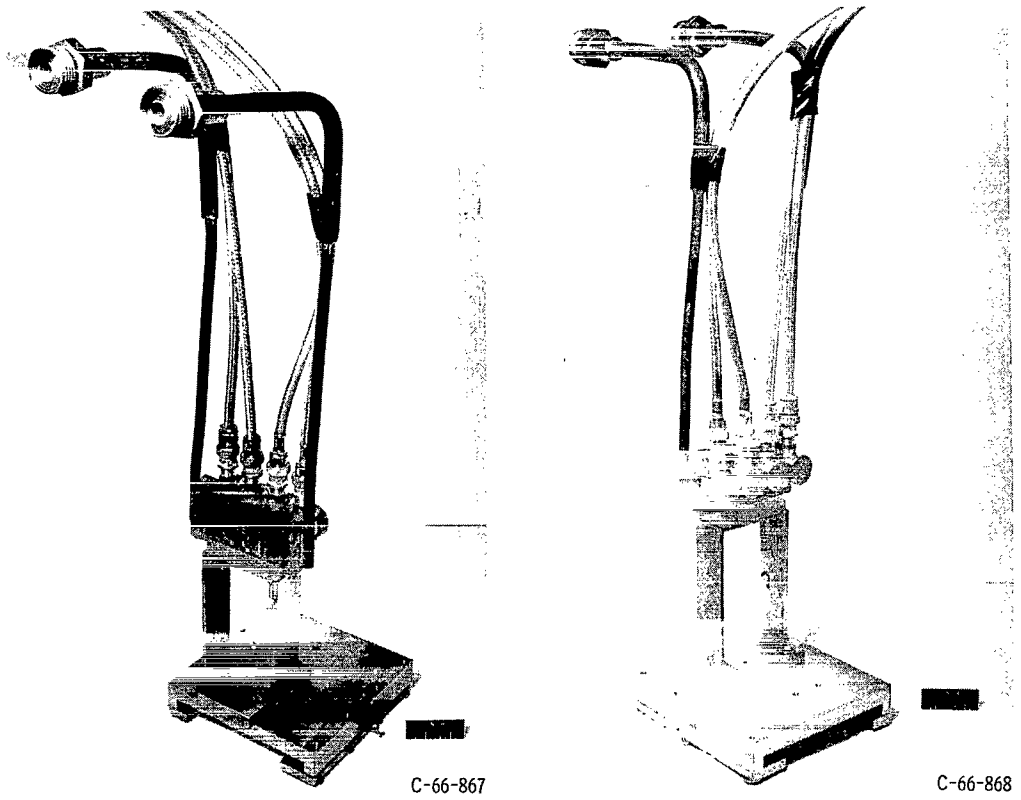


Figure 20. - Response of 2700-micron-thick lithium-drifted counter to 19-MeV protons accelerated in University of Colorado cyclotron (ref. 2).



(a) Front view. (b) Rear view.

Figure 21. - Four-counter holder used in scattering chamber of Lewis cyclotron.

results in figure 20, it should be recognized that accelerator scattering systems capable of 10-keV resolution work, when magnetic analysis is used for the reaction product particles, could readily achieve 25-keV overall resolution with these counters, even for reaction product particles with energies whose range equivalence is at least as great as that of 35-MeV protons.

The desirability of having a clean vacuum in which to cool the counter should prompt the users of accelerator scattering chambers to consider seriously pumping systems other than oil-diffusion pumps. Several possible schemes are turbomolecular pumps or ion pumps to hold a vacuum after blanking off a diffusion pump that was used to evacuate the chamber rapidly.

A convenient four-counter holder for the simultaneous collection of scattering data at four different angles is shown in figure 21. This multicounter holder is commonly used for data collection at the Lewis cyclotron. Each counter is 4^{o} away from its

neighboring counters when the counter slits are positioned 9.76 inches from the target. The counter slits are positioned by pins mounted on the holder cooling block.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 26, 1966,
129-02-04-06-22.

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2. Anon: Technical Progress Rep. UCOL-535-552, University of Colorado, Dept. of Physics and Astrophysics, Nov. 1, 1965, p. 20. (Contract no. AT-(11-1) -535.)

NASA-Langley, 1966 E-3432