Specification for Thick Silicon Detectors for the EPI-Hi Instrument for Solar Probe Plus

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1. **Applicability.**
   - This specification applies to conventional silicon solid-state detectors for use in the EPI-Hi Low-Energy Telescope (LET) and High-Energy Telescope (HET) sensors being developed for NASA's Solar Probe Plus mission.
2. **Designations.**
   - Two different LET detector types are specified. They are designated L2 and L3. In addition, three different HET detector types are specified, with designations H1, H2, and H3. Requirements for each of these detector types are discussed in the following paragraphs and summarized in Table 1. Figures 1a through 1e illustrate the detector geometries.
3. **Technology.**
   - Detectors shall be fabricated by ion implantation of crystalline n-type silicon. The silicon shall have a $\langle 100 \rangle$ crystal orientation. Detectors are to be fabricated using conventional lapped and polished silicon wafers
4. **Operation.**
   - Detectors will be operated fully depleted in a transmission-type configuration. Signals will be taken from the junction (p^+) surface, which will be operated near ground potential; the ohmic (n^+) surface will be operated at a positive bias.
5. **Active Element Shapes and Sizes.**
   - The active areas of the detectors shall be segmented into various numbers of signal elements, as follows:
     - ▷ The L2 design shall contain 7 active elements, consisting of a central bull's eye of diameter 5.0 mm surrounded by 4 quadrants of a ring with outside diameter of 11.3 mm. These 5 equal-area elements shall be surrounded by an additional ring having outside diameter of 24.5 mm. A small, square pixel with dimensions of 0.6 mm× 0.6 mm shall be located near the outer periphery of the ring. The L2 design is illustrated in Figure 1a.
     - ▷ The L3 design shall contain 3 active elements, consisting of a central circular area of diameter 11.3 mm surrounded by a ring having an outer diameter of 24.5 mm. A small, square pixel with dimensions of 1.0 mm× 1.0 mm shall be located near the outer periphery of the ring. The L3 design is illustrated in Figure 1b.
     - ▷ The H1 design shall contain 7 active elements. A central bull's eye of diameter 5.0 mm shall be surrounded by 4 quadrants of a ring with outside diameter of 11.3 mm. These 5 equal-area elements shall be surrounded by an additional ring having outside diameter of 14.3 mm. A small, square pixel with dimensions of 0.6 mm× 0.6 mm shall be located near the outer periphery of the ring. The H1 design is illustrated in Figure 1c.

- ▷ The H2 design shall contain 7 active elements. A central bull's eye of diameter 5.0 mm shall be surrounded by 4 quadrants of a ring with outside diameter of 11.3 mm. These 5 equal-area elements shall be surrounded by an additional ring having outside diameter of 17.3 mm. A small, square pixel with dimensions of 1.0 mm× 1.0 mm shall be located near the outer periphery of the ring. The H2 design is illustrated in Figure 1d.
- ▷ The H3 design shall contain 3 active elements. A circular central area of diameter 11.3 mm shall be surrounded by a ring having outside diameter of 17.3 mm. A small, square pixel with dimensions of 1.0 mm× 1.0 mm shall be located near the outer periphery of the ring. The H3 design is illustrated in Figure 1e.

6. **Chip Shape and Area.**
   - The completed chips shall be 16-sided regular polygons. The flat-to-flat dimensions of the chips shall be as follows: L2, 27.5 mm; L3, 28.5 mm; H1, 17.3 mm; H2, 21.3 mm; H3, 21.3 mm.
7. **Orientation on Wafer.**
   - The detector chips shall all be fabricated with the same fixed orientation relative to the flats on the silicon wafers to within $\pm 1°$.
8. **Guard Rings and Field Plates.**
   - The detectors shall include structures such as floating multi-guard rings and field plates to be designed by the manufacturer to optimize detectors for achieving low leakage current and low noise over the specified range of operating voltages.
9. **Contacts.**
   - The active elements of each detector shall be connected by narrow traces to wire bonding pads located near the periphery of the chip. In some cases this will require that the trace pass through a narrow gap between or through surrounding element(s). The widths of such gaps should be kept to the minimum required for good detector performance. The manufacturer shall propose a design for the traces and wirebond pads.
10. **Active Thickness.**
    - The L2 and H1 detectors shall each be supplied in two different thicknesses, 500 μm $\pm 30\,\mu$m and 720 μm $\pm 30\,\mu$m. The L3, H2, and H3 detectors shall each be supplied in a single thickness of 1000 μm $\pm 30\,\mu$m.
11. **Thickness Knowledge.**
    - The manufacturer shall report the measured thicknesses of each detector to an accuracy of $\pm 2\,\mu$m. This measurement can be made on silicon pieces that remain when the chips are diced out of the silicon wafer. Such "offcuts" shall be obtained from close enough to each detector to be representative of the detector thickness to this accuracy.
12. **Thickness Variation.**
    - The total thickness variation over the active area of each detector shall not exceed the following values: $\pm 2.5\,\mu$m for the 500 μm detectors, $\pm 3.5\,\mu$m for the 720 μm detectors, and $\pm 5\,\mu$m for the 1000 μm detectors.

13. **Segment Isolation.**
    - The DC resistance between each active electrode and all other active electrodes on the junction surface of the reverse-biased detector shall be greater than 10 MΩ, with a goal of greater than 100 MΩ.
14. **Dead Layers.**
    - The junction and the ohmic surfaces of the detector shall each have dead layers of thickness $<1\,\mu$m due to surface implants and metallization.
15. **Metallization.**
    - The detector surfaces shall be metallized with aluminum having 3000±500 Å thickness.
16. **Surface Condition.**
    - Detectors shall have specular reflecting (mirror) surfaces of good quality.
17. **Design Review and Approval.**
    - The manufacturer shall carry out the detailed design of the detectors and submit drawings to the EPI-Hi team for approval prior to the fabrication of photolithography masks and fixturing.
18. **Detector Mounting.**
    - Transmission-style detector mounts will be designed and procured by NASA's Goddard Space Flight Center and supplied to the detector manufacturer. The detector manufacturer shall review and approve the detector mount specification and design drawings prior to fabrication. Detector mounts will be fabricated as multilayer polyimide circuit boards that will include flex-circuit leads having appropriate connectors for mating to external circuitry. Detector chips shall be installed by the manufacturer in the detector mounts using Shin-Etsu KJR-9022E resin mixed and cured according to Shin-Etsu instructions. An alternative mixing and curing procedure is acceptable, if approved by NASA.
19. **Mounting Tolerances.**
    - The detector chips shall be installed in the mounts in such a way as to maintain the following tolerances: parallelism between chip and mounting ledge, $\pm 1°$; concentricity between chip and detector mount, $\pm 100\,\mu$m; rotational accuracy relative to the symmetry axis perpendicular to the plane of the detector, $\pm 0.5°$. During the design of the detector mask set and the detector mounts the manufacturer and the EPI-Hi team shall consult to agree upon any design features required to meet these requirements.
20. **Electrical Connections.**
    - Electrical connections between detector contacts and associated pads on the detector mount shall be made using 3 separate wire bonds per connection. Wire bonding shall be done using soft aluminum wire with a nominal diameter of $25\,\mu$m. Wire bond lengths shall be kept as short as practical with a goal of <3 mm. The wirebond pads on the detectors shall be large enough to accommodate the future addition of 2 additional wirebonds, should repairs be required. The size of the wirebonding pads shall not significantly exceed the area required to accommodate the initial 3 bonds plus the spaces for addition of 2 more bonds.

- A non-destructive pull test shall be performed by the manufacturer on 1 of the bonded wires connected to each detector contact using a force corresponding to the pull of a 3 gram weight. In addition, each detector mount supplied to the detector manufacturer will be accompanied by a wirebonding test sample. When the detector chips are being wirebonded to the mount, additional bonds are to be made to this test sample. These test bonds are to be subjected to a destructive pull test. The highest force applied before the bond breaks shall be recorded and reported as part of the detector data package. The pull at which the test bonds fail shall be no less than 7 grams. A minimum of 2 wires bonded at each end are to be destructively tested in this way before wirebonds are made on the detector and another 2 wires are to tested after the wirebonding of the detector has been completed.
- An important requirement for the HET and LET sensors is to have close spacings between successive detectors in the telescope stacks. The maximum allowable gap between successive detectors in a stack (bottom surface of one detector to top surface of the next detector) is 0.5 mm. The wire bonds used for connecting the detector elements to corresponding pads on the detector mount shall not extend more than 350 μm above the bonding pad on the mount. This requirement is imposed in order to minimize the chance of electrical breakdown between the wirebond and the surface of the adjacent detector when the detector telescope is operated in a dry nitrogen environment.

21. **Full-Depletion Voltage.**
    - The maximum full-depletion voltage, V_d, for the various detector thicknesses shall be as follows: 45 V for the 500 μm detectors, 90 V for the 720 μm detectors, and 175 V for the 1000 μm detectors.
    - The detector depletion characteristics shall be measured in two ways. First, the detector capacitance shall be measured as a function of applied bias to determine the bias at which the capacitance has essentially reached its asymptotic value. Second, alpha particle spectra shall be measured in vacuum with alphas incident from each surface of the detector with the required maximum full depletion voltage applied. The measured distributions of deposited alpha particle energies shall have comparable means and standard deviations from both surfaces. The setup to be used for alpha particle measurements is discussed below (see "Alpha Particle Resolution").
22. **Breakdown Voltage.**
    - The minimum breakdown voltage for the various detector thicknesses shall be as follows: 150 V for the 500 μm detectors, 200 V for the 720 μm detectors, and 250 V for the 1000 μm detectors.
    - The breakdown voltage shall be defined as the lowest reverse bias at which the leakage current exceeds 1 μA.
23. **Leakage Current.**
    - The maximum allowable leakage currents at 20°C shall be as follows: for the 500 μm detectors, 75 nA; for the 720 μm detectors, 100 nA; for the 1000 μm detectors, 150 nA. For determining whether these specifications have been met, leakage currents shall

be measured with all detector segments connected in parallel and with the detector biased at least 30 V above the full-depletion voltage. These measurements shall be made at room temperature in a vacuum $< 4 \times 10^{-4}$ torr after the detector has been allowed to stabilize for at least 1 hour. The leakage current specification shall be met within 30 sec of bias being applied. The leakage currents shall not exceed the values listed by more than a factor of 2 for a period of at least 1 year after delivery.

24. **Forward Bias.**
   - The forward bias voltage at which the detector current reaches 1 mA shall be no greater than 0.8 V.
25. **Alpha Particle Resolution.**
   - Measurements of detector resolution shall be made in a vacuum using an alpha particle source (e.g., ^{241}Am or ^{244}Cm). The source shall be positioned at least 10 cm from the detector and shall illuminate the entire active area of the detector. The resulting pulse height distribution from the detector shall be measured with all detector segments connected in parallel using a charge sensitive amplifier, a shaping amplifier having peaking time (zero to peak) in the range 1 to 4 μs, and a pulse height analyzer. Measurements made with the alpha particles incident on each of the detector surfaces shall be reported. The alpha particle resolution, defined as the FWHM of the measured alpha peak, shall not exceed the following values: for the 500 μm detectors, 75 keV; for the 720 μm detectors, 65 keV; for the 1000 μm detectors, 55 keV.
26. **Temperature Range.**
   - The detectors shall shown to have an operating temperature range of at least −40°C to +40°C and a non-operating temperature range of at least −60°C to +60°C. They shall meet the performance specifications after being returned to 20°C after exposure to each of the non-operating temperature extremes for at least 1 hour in a dry nitrogen atmosphere at ambient pressure.
27. **Radiation Hardness.**
   - The detectors shall be designed to remain suitable for use after being subjected to proton radiation doses of up to 1 Mrad.
28. **Thermal-Vacuum Stability.**
   - The detectors shall be tested for at least 21 days at +40°C in a vacuum of $< 4 \times 10^{-4}$ torr with the detectors continually biased to at least 30 V above the full-depletion voltage. The leakage current shall be monitored on a regular basis throughout the test. To pass this test the leakage current must not increase by more than 10% over the last 10 days of the test. A record of the time dependence of the leakage current and, if possible, the electronic noise, shall be included as part of the documentation package to be delivered with each detector.
29. **Thermal Cycling.**
   - The detectors shall be cycled at least 1 time between temperatures of −60°C and +60°C and back at a rate of approximately 2°C per minute. This test shall be performed with no bias applied in a dry nitrogen atmosphere. Visual inspections and

electrical tests shall be carried out to establish that the performance of the detectors has not been degraded due to the thermal cycling.

30. **Random Vibration Testing.**
    - The detectors shall be subjected to a three-axis random vibration test with one of the acceleration axes normal to the detector surface. The power spectrum, overall level, and duration shall be as given in Table 2.
    - The detectors shall be thoroughly inspected after the vibration test for cracks, detached wire bonds, or other damage. Any observed damage shall be reported to the EPI-Hi team. The damaged detectors shall, at the discretion of the EPI-Hi team, be delivered for further inspection.
31. **Detector Identification.**
    - Each detector mount delivered to the detector manufacturer will have been marked with a unique identification number. This number shall be included on each data item delivered with the detector and shall be cited in all communications about a particular detector.
32. **Documentation Package.**
    - Each delivered detector shall be accompanied by a documentation package containing information about the detector fabrication and testing. At a minimum this package shall contain the following:
      1) detector identification number,
      2) original delivery date (month and year),
      3) wafer ID number and copy of the wafer manufacture's data sheet for the silicon wafer from which the detector was fabricated,
      4) detector thickness as measured from offcuts,
      5) results of wirebond pull tests,
      6) plot of detector capacitance versus bias,
      7) plot of detector leakage current versus bias measured at room temperature and atmospheric pressure,
      8) depletion voltage,
      9) breakdown voltage,
      10) measured inter-electrode resistance,
      11) alpha particle and test pulser pulse-height spectra measured with the alpha particles incident on the junction side and on the ohmic side of the detector and alpha-particle resolution derived from these data,
      12) documentation and any applicable certificates from the environmental tests (temperature range, thermal-vacuum stability, thermal cycling, random vibration),
      13) copy of the manufacture's batch traveller documenting the sequence of fabrication and testing steps that the detector has gone through.
    - The measurement results shall be reported in a standard format to be agreed upon by the detector manufacturer and the EPI-Hi team.

Table 1.
Solar Probe Plus EPI-Hi Instrument Silicon Detector Key Requirements Summary*
Detectors for the Low-Energy Telescope (LET):

Design ID:	L2	L3
Thicknesses**:	$500\,\mu$m$\pm 30\,\mu$m $720\,\mu$m$\pm 30\,\mu$m	$1000\,\mu$m$\pm 30\,\mu$m
Chip Shape:	16-sided polygon	16-sided polygon
Chip Size (flat-to-flat):	27.5 mm	28.5 mm
Active Segments:	7	3
Segment Geometry:	Figure 1a	Figure 1b
Thickness Variation**:	$\leq\pm 2.5\,\mu$m $\leq\pm 3.5\,\mu$m	$\leq\pm 5\,\mu$m
Full-Depletion Voltage**:	$\leq$45 V $\leq$90 V	$\leq$175 V
Breakdown Voltage**:	$\geq$150 V $\geq$200 V	$\geq$250 V
Leakage Current (20°C):	$\leq$75 nA $\leq$100 nA	$\leq$150 nA

Notes:

* This table summarizes only selected requirements. See the accompanying text for additional requirements.

** When two values are given for a parameter, the first applies to the $500\,\mu$m detectors and the second to the $720\,\mu$m detectors.

Table 1 (continued).
Solar Probe Plus EPI-Hi Instrument Silicon Detector Key Requirements Summary*
Detectors for the High-Energy Telescope (HET):

Design ID:	H1	H2	H3
Thicknesses**:	$500\,\mu$m$\pm 30\,\mu$m $720\,\mu$m$\pm 30\,\mu$m	$1000\,\mu$m$\pm 30\,\mu$m	$1000\,\mu$m$\pm 30\,\mu$m
Chip Shape:	16-sided polygon	16-sided polygon	16-sided polygon
Chip Size (flat-to-flat):	17.3 mm	21.3 mm	21.3 mm
Active Segments:	7	7	3
Segment Geometry:	Figure 1c	Figure 1d	Figure 1e
Thickness Variation**:	$\leq\pm 2.5\,\mu$m $\leq\pm 3.5\,\mu$m	$\leq\pm 5\,\mu$m	$\leq\pm 5\,\mu$m
Full-Depletion Voltage**:	$\leq$45 V $\leq$90 V	$\leq$175 V	$\leq$175 V
Breakdown Voltage**:	$\geq$150 V $\geq$200 V	$\geq$250 V	$\geq$250 V
Leakage Current (20°C):	$\leq$75 nA $\leq$100 nA	$\leq$150 nA	$\leq$150 nA

Notes:
- * This table summarizes only selected requirements. See the accompanying text for additional requirements.
- ** When two values are given for a parameter, the first applies to the $500\,\mu$m detectors and the second to the $720\,\mu$m detectors.

Table 2. Random Vibration Test Specification

Frequency (Hz)	Power Density (G^2/Hz)
20	0.01
60	1.25
200	1.25
350	0.04
500	0.04
1000	0.01
Overall Grms	16.4
Duration (mins)	1

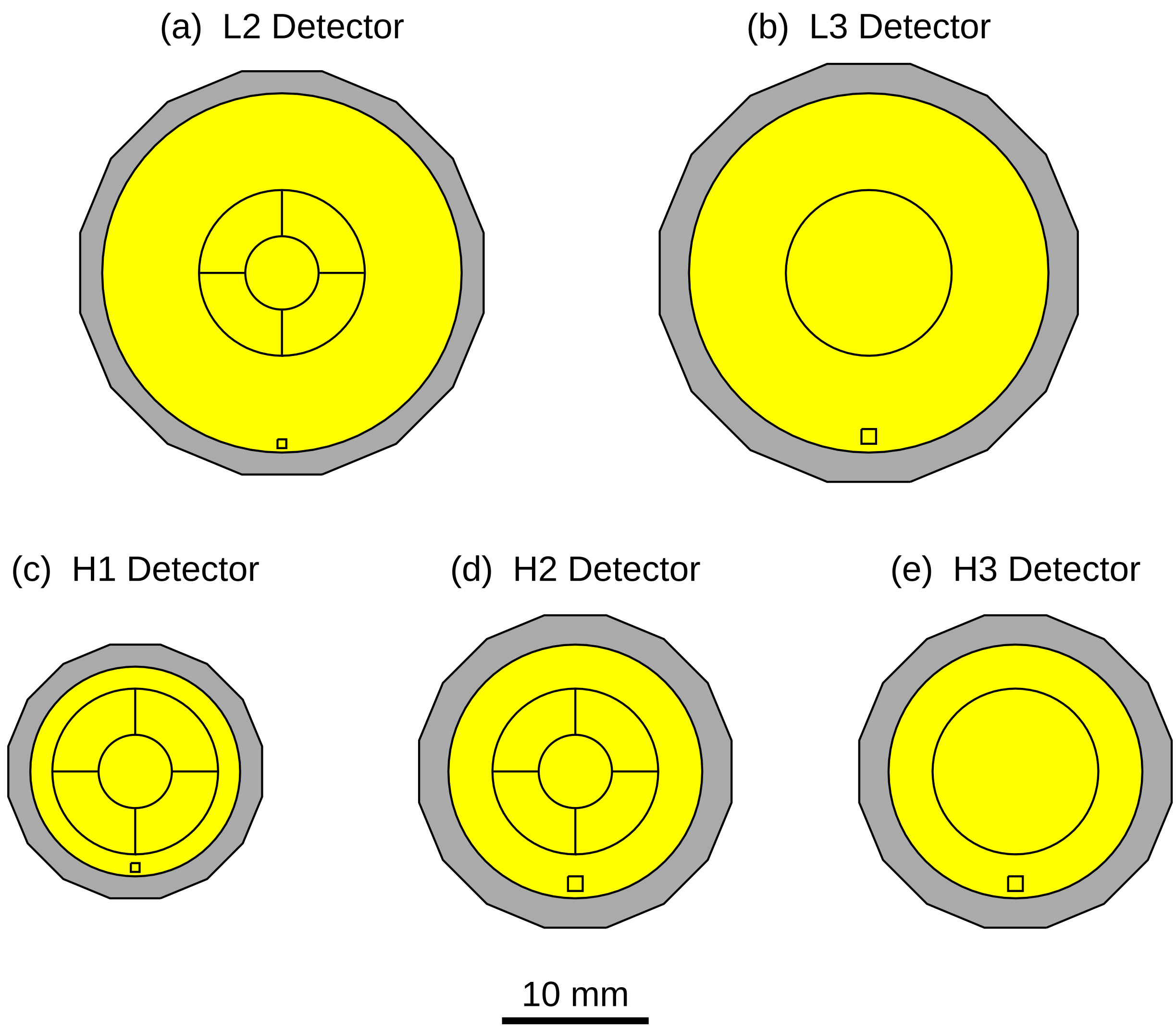

Figure 1. Illustration of required segmentation of the detectors. The yellow indicates active silicon elements and the grey indicates the inactive peripheries of the chips. Detailed dimensions are given in the text. This drawing does not show the tracks required to connect the detector elements to wirebonding pads nor the pads themselves. Those details are to be worked out between the manufacturer and the EPI-Hi team. The exact placement of the small, square pixel is also to be worked out.