Specification for Thick/Thin Silicon Detectors for the EPI-HI Instrument for Solar Probe Plus

Version 1.02, 31 July 2012

1. **Applicability.**
   - This specification applies to thin, silicon solid-state detectors for use in the EPI-Hi LET telescopes to be developed for NASA's Solar Probe Plus (SPP) mission.
2. **Detector Designations.**
   - Two different detector types are specified. They are designated L0 and L1.
3. **Technology.**
   - Detectors shall be fabricated by ion implantation of crystalline silicon. The silicon shall have a ⟨100⟩ crystal orientation. Detectors are to be fabricated using thick/thin technology based on silicon-on-insulator (SOI) wafers. The active thickness of the detectors shall be controlled by the thickness of the SOI device layer, with the SOI's buried oxide layer being used as an etch stop in achieving this thickness.
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 at ground potential; the ohmic (n^+) surface will be operated at a positive bias.
5. **Active Element Geometry.**
   - The overall active area of each detector shall be a circle of diameter 11.3 mm (providing a 100 mm^2 total active area). On the junction surface this area shall be subdivided into 5 equal-area segments, a central bull's eye of diameter 5.0 mm surrounded by 4 quadrants of a ring, as illustrated in the accompanying figures. The gaps between adjacent active detector segments shall be kept as narrow as practically achievable. The manufacturer shall advise the EPI-Hi team of the proposed gap width.
6. **Thin Membrane Shape and Area.**
   - The thin Si membrane on which the detectors are fabricated shall extend outside the area occupied by the active elements of the detector and any surrounding floating guard rings (see below). For L1, the excess radius shall be sufficient to allow easy alignment of the patterning used for thinning the SOI with the patterning used for producing the detector elements. For L0, the thin membrane shall have a diameter of 34 mm, which is significantly larger than the active diameter of the detector.
7. **Chip Size and Shape.**
   - The overall shape of the detector chips shall be 16-sided regular polygons. The size of the L1 chip shall be 28 mm measured from flat to flat. The size of the L0 chip shall be 45.5 mm measured from flat to flat.
8. **Orientation.**
   - The detector chips shall be fabricated with a fixed, specified orientation relative to the primary and secondary flats on the device layer of the SOI wafer.

9. **Guard Rings.**
   - The manufacturer shall provide recommendations concerning the advisability of including a set of narrow, floating guard rings surrounding the detector active area.
10. **Contacts.**
    - Each of the 5 active segments shall be connected by a narrow trace to a wire bonding pad located on the thick portion of the wafer. The trace connected to central bull's eye segment of the detector shall be routed between between two of the surrounding four segments.
    - On the L0 detectors these traces will need to be relatively long due to the larger diameter of the thin membrane relative to that of the active area. The manufacturer shall provide advice on the desirability of isolating these traces from the silicon.
11. **Active Thickness.**
    - In their active regions the L0 detectors shall have an overall thickness of $12 \pm 0.5\,\mu$m and the L1 detectors shall have an overall thickness of $25 \pm 0.5\,\mu$m. These thicknesses shall correspond to the device layer thickness specified for the SOI wafers.
12. **Thickness Uniformity.**
    - Good thickness uniformity is a high priority. The uniformity goal is <1% thickness nonuniformity over the 100 mm^2 active areas. The SOI wafers shall be specified to have a device layer thickness that varies by no more than $0.5\,\mu$m microns over the entire wafer and the SOI wafer order shall specify that the manufacturer attempt to achieve uniformity better than $0.2\,\mu$m on a best-effort basis. Etching and other processing of the wafers shall be carried out in such a way as to not significantly degrade the thickness uniformity from that of the SOI device layer.
13. **Handle Wafer Thickness**
    - The handle wafer used in fabricating the SOI shall have a nominal thickness of $300\,\mu$m.
14. **Segment Isolation.**
    - The DC resistance between each active electrode and all other active electrodes on the junction surface of the detector shall be greater than 10 MΩ, with a goal of greater than 100 MΩ.
15. **Dead Layers.**
    - The junction and the ohmic surfaces of the detector shall each have dead layers of thickness $0.5\,\mu$m ("Type 2 Window") due to ion implantation.
16. **Metallization.**
    - The detector active elements shall be metallized with a uniform sputtered aluminium coating having a nominal thickness of 3000 Å. Thicker aluminization outside the active area is acceptable.
17. **Surface Condition.**
    - The detectors shall have specular reflecting (mirror) surfaces of good quality.
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 prior to fabrication of the mounts. It is anticipated that detector mounts will be fabricated as multilayer circuit boards using polyimide and flexible Kapton leads with appropriate connectors for mating to external circuitry. Detector chips shall be installed in the detector mounts using Shin-Etsu KJR-9022E resin. The resin shall be mixed and cured according to manufacturer's 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, $<1°$; translational accuracy in the plane of the detector <0.2 mm; rotational accuracy about an axis perpendicular to the plane of the detector, $<0.5°$.

20. **Electrical Connections.**
   - Electrical connections between detector contacts and nearby pads on the detector mount shall be made using a minimum of 4 separate wire bonds per connection. Wire bonding shall be done using soft aluminum wire with a nominal diameter of 25 μm. Wire bond lengths shall be kept as short as practical with a goal of $<$ 3 mm. The minimum bond strength shall correspond to the pull of a 3 gram weight. A non-destructive pull test shall be performed by the manufacturer on one of the detector bonds connected to each detector contact to demonstrate compliance with this specification.

21. **Depletion Voltage.**
   - The maximum depletion voltage, V_d, for the two detector types shall be as follows: for L0, 2 V; for L1, 4 V.

22. **Breakdown Voltage.**
   - The minimum acceptable breakdown voltages for each of the two detector types shall be 25 V. The breakdown voltage shall be determined from measurements of the detector's leakage current (I) versus reverse bias (V) with all detector segments connected in parallel. The breakdown voltage shall be taken to be the lowest value of V for which I exceeds 100 nA.

23. **Leakage Current.**
   - The maximum allowable leakage current shall be: for L0, 2 nA, for L1, 4 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 5 V above the full depletion voltage. These measurements shall be made at room temperature in a vacuum $<5\times10^{-6}$ torr after the detector has been allowed to stabilize for at least 1 hour. The leakage current specification shall be met within 30 seconds of bias being applied. The leakage currents shall not exceed the values listed above by more than a factor of 2 for a period of at least 1 year after delivery.

24. **Alpha Particle Resolution.**
   - The range of alpha particles from typical sources (e.g., ^{241}Am or ^{244}Cm) is longer than the thickness of the L0 and L1 detectors. To obtain a measurement of the detector

resolution, the alpha particles shall be collimated in a narrow beam and allowed to penetrate a thin, uniform energy-degrader foil (e.g., aluminum) prior to impinging on the detector. The foil thickness shall be such that alpha particles penetrate between 50% and 90% of the nominal detector thickness. The resulting pulse height 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. The alpha particle resolution shall not exceed 55 keV FWHM, after correcting for the energy spread of the source and additional broadening introduced by the degrader foil.

25. **Design Temperature Range.**
    - The detectors shall be designed for operation over a temperature range of −40°C to +40°C and survival over a non-operating temperature range of −60°C to +60°C.
26. **Temperature Testing, Non-operating Range.**
    - Testing over the non-operating range shall be performed either in a dry nitrogen atmosphere or in a vacuum 5×10^{-6} torr or better. A thermal soak of at least 1 hour at each of the temperature extremes shall be performed. The detectors shall meet the performance specifications after being returned to 20°C following exposure to the non-operating temperature extremes.
27. **Thermal Testing, Operating Range.**
    - The detectors shall be cycled at least 10 times between the operational temperature extremes at a rate of approximately 2°C/minute. This test shall be performed with no bias applied in a dry nitrogen atmosphere or in a vacuum of 5×10^{-6} torr or better.
28. **Vacuum Stability.**
    - The detectors shall be tested for at least 72 hours at the maximum operating temperature (+40°) in a vacuum of 5×10^{-6} torr or better with the detectors continually biased to at least 1 V above the depletion voltage. The leakage current and, if possible, the electronic noise, shall be monitored throughout this test and the measurements reported as part of the documentation package to be delivered with the detector.
29. **Radiation Hardness.**
    - The detectors shall be designed to remain suitable for use after being subjected to proton radiation doses of up to 100 krad.
30. **Random Vibration Testing.**
    - The detectors shall be subjected to a single-axis random vibration test with the acceleration axis normal to the detector surface. The test shall be performed with a vibration spectrum (to be provided) extending from 20 Hz to 2 kHz with an overall amplitude of 16.4 g rms. The test duration shall be 2 minutes. After the vibration test the detectors shall be thoroughly inspected for cracks, detached wire bonds, or other damage.
31. **Acoustic Testing.**
    - Acoustic testing of all of the L0 and L1 detectors are planned after receipt from the manufacturer using an acoustic spectrum and an overall amplitude suitable for the

Solar Probe Plus launch. For the acoustic test the detectors will be mounted in a fixture that will approximate the acoustic response of the EPI-Hi instrument. This fixture will be designed and fabricated by the EPI-Hi team. The detectors will be thoroughly inspected after the test for cracks, detached wire bonds, or other damage. If so desired, the detector manufacturer may propose an option for performing the acoustic testing prior to detector delivery.

32. **Detector Identification.**
    - Each detector shall have a unique, 2-digit identification number written on the mount with an indelible ink compatible with use near solid-state detectors. This serial number shall be used to label all data to be included in the documentation package to be delivered with the detector.
33. **Documentation Package.**
    - Each delivered detector shall be accompanied by a documentation package containing information about the detector fabrication and testing. As a minimum, this package shall contain the following: 1) detector identification number, 2) original delivery date (month and year), 3) ID number of the SOI wafer from which the detector was fabricated, 4) copy of the specifications and data sheet for the SOI wafer obtained from the SOI manufacturer, 5) copy of the batch traveler documenting the detector fabrication and testing steps, 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) 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 using the procedures described above, 11) alpha particle resolution calculated from the measurements, 12) environmental test results. The measurement results shall be reported in a standard format to be agreed upon by the detector manufacturer and the EPI-Hi team.

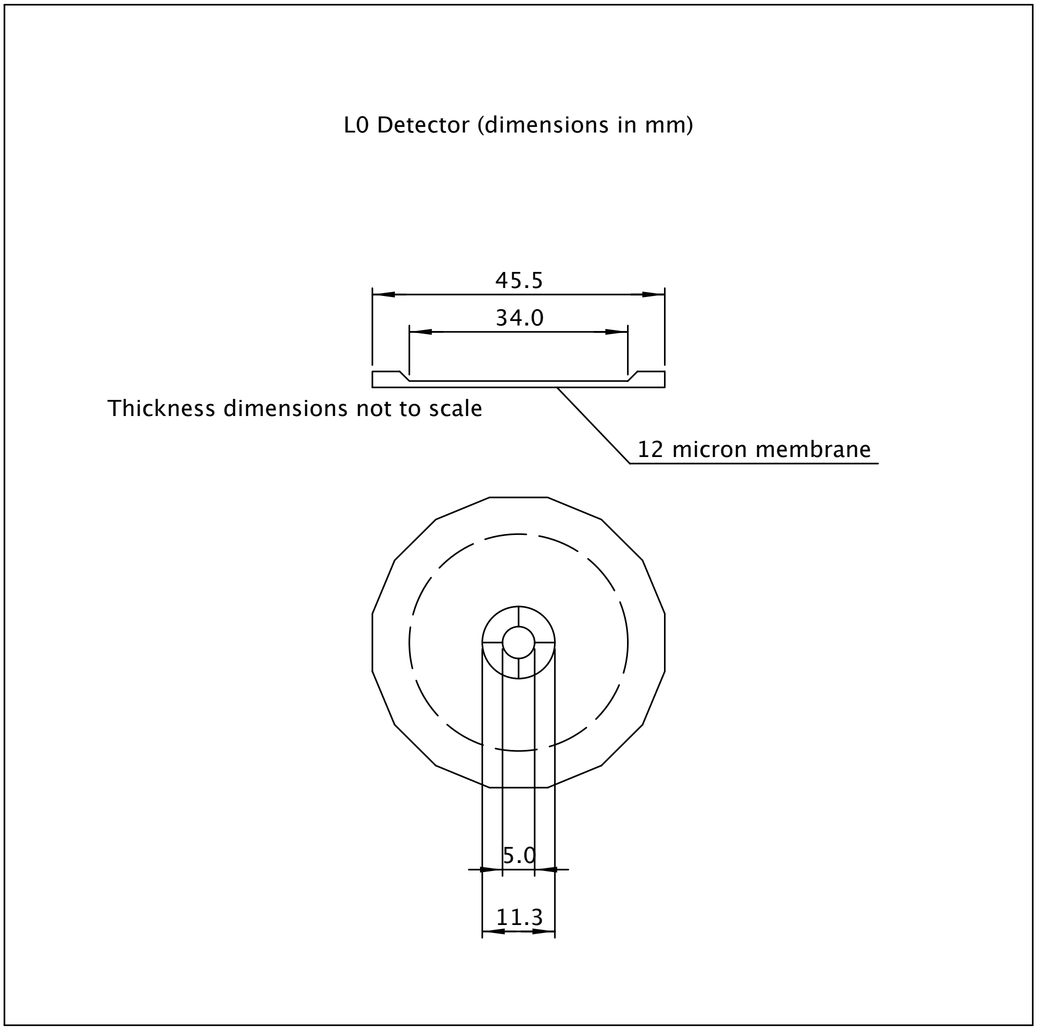
L0 Detector (dimensions in mm)
45.5
34.0
Thickness dimensions not to scale
12 micron membrane
5.0
11.3

Figure 1.

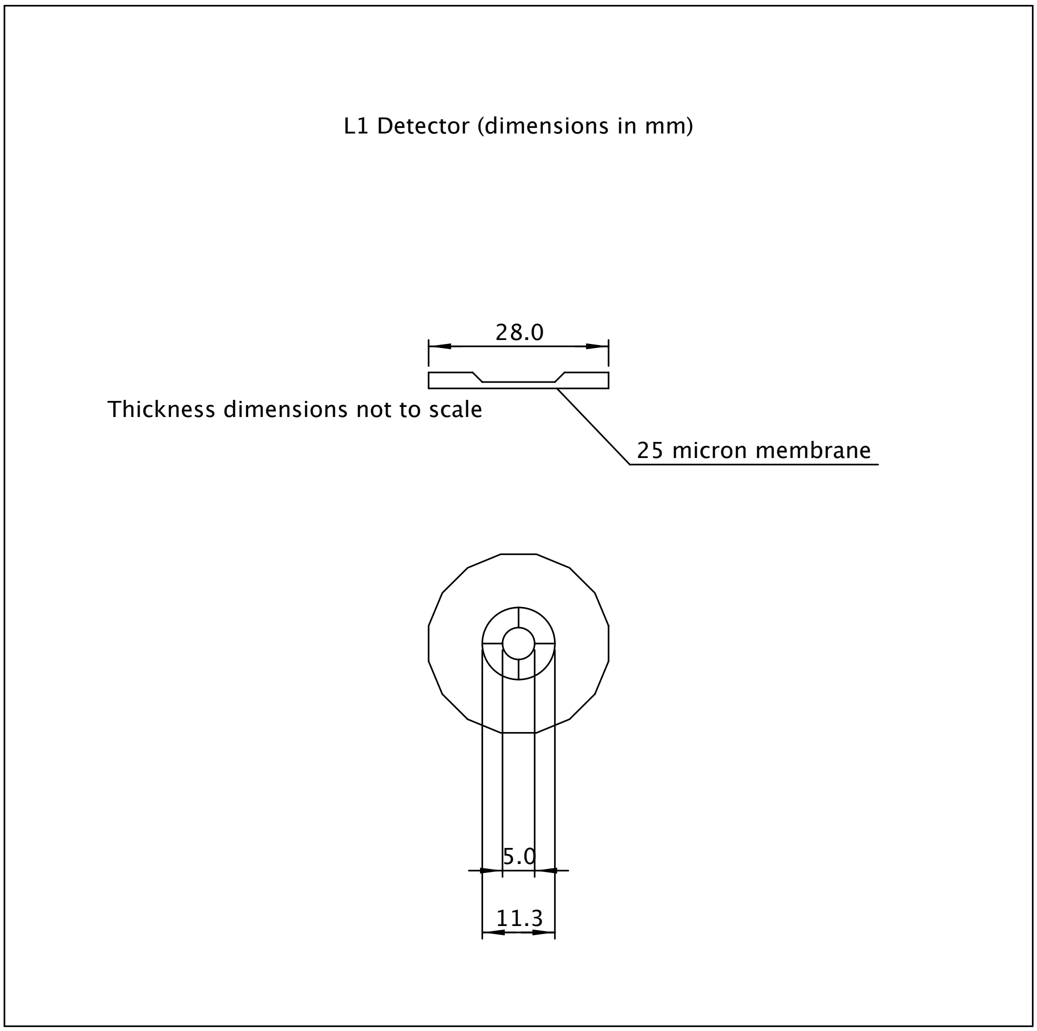
L1 Detector (dimensions in mm)
28.0
Thickness dimensions not to scale
25 micron membrane
5.0
11.3

Figure 2.