Please refer to supplementary document for Methods and Calculations: Supplemental Calculations Document

Fabrication of Germanium wafers by proton implantation cutting and beam writing

The Super Slicers

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I. Why we want to go

As driven students from TJHSST, we express enthusiasm for STEM subjects, taking a special interest in the realm of quantum physics. Every member of our team holds aspirations for a future career in physics, and our participation in this competition has already allowed us to hone research skills that are necessary in the field. Collaborating with CERN professionals would be a pivotal experience in our journey, providing the expertise for us to join the next generation of particle physicists and engineers.

II. Our Proposal

2.1 Ion-cutting Germanium

Ion-cut amorphous Germanium (a-Ge) can be incorporated into tandem solar cell configurations, where multiple semiconductor layers with different band gaps are stacked to enhance light absorption and efficiency by capturing a broader spectrum of sunlight [4].

To achieve micrometer thicknesses, Germanium wafers are usually cut using an ultrathin diamond cutter, which unfortunately results in kerf losses of 30% to 40% of the initial material. Furthermore, the minimum thickness of Germanium lamina with sawing is over 115 μm, limiting applications for ultrathin solar cells.

We propose using the proton implantation to achieve ultrathin cutting of Germanium. We plan to use the Linac4 accelerator with a current of 20 proton bunches and a varied velocity (**Figure 1**). The beam will implant protons into the Germanium to a depth corresponding to the proton's kinetic energy as calculated by Bethe's law. Once a sufficient dose of protons has been implanted into the Germanium, we will extract the wafer to be annealed at 450ºC (under the crystallization temperature) for a couple minutes (we plan to be flexible with the annealing time because of the lack of previous similar experiments). The ion-cutting process is shown in **Figure 2**.

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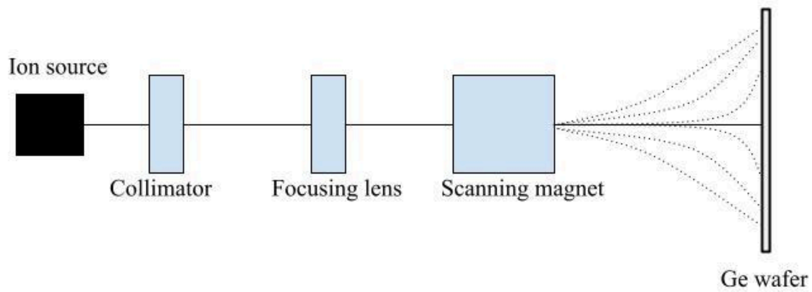

Figure 1: *Experimental setup to focus proton beam and redirect trajectory to slice Ge wafer*

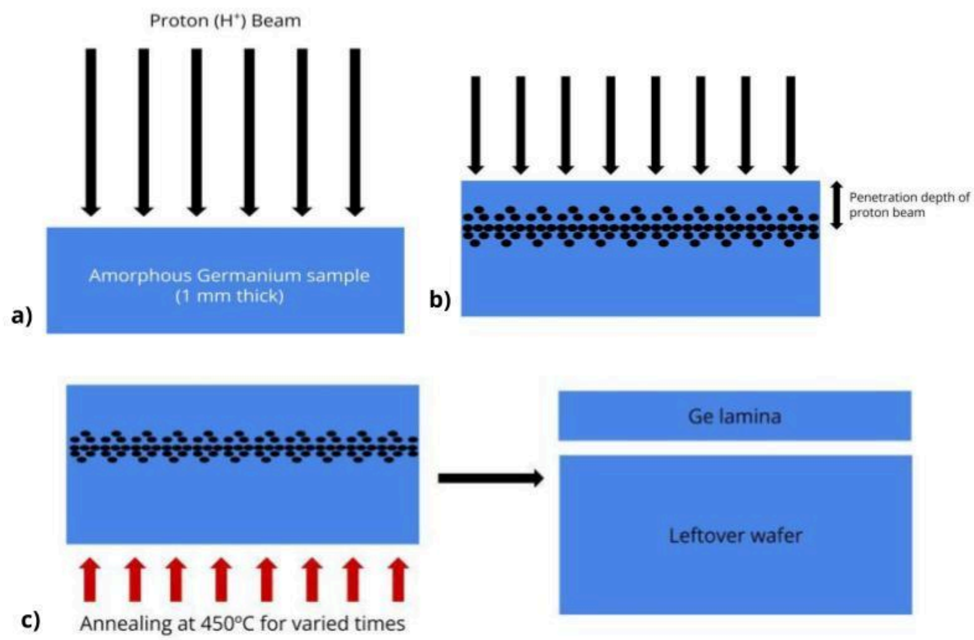

Figure 2: *Proton cutting process a) the proton beam penetrates the Ge sample b) protons are implanted to the desired depth of the Germanium wafer c) annealing exfoliates a thin lamina from the rest of the wafer.*

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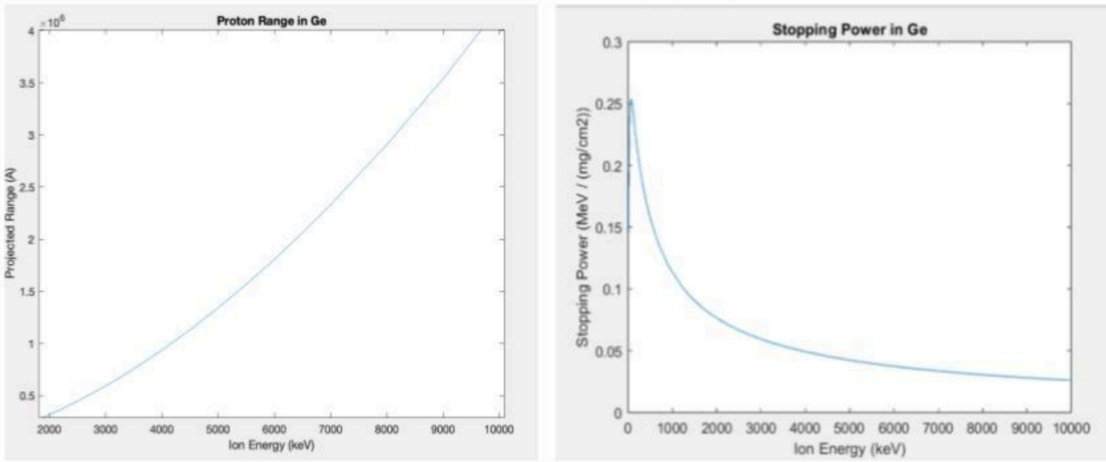

a) b)

***Figure 3**: The full table as predicted by the SRIM software is provided in the supplemental document. a) Hydrogen ion energy vs penetration range in germanium. b) Hydrogen ion energy vs stopping power in germanium.*

	Proton energy (MeV)	**Stopping power (MeV mg/cm^2)**	**Velocity through penetration (m/s)**	**Stopping time (s)**
0.106 µm	0.012	0.1454	1,073,153.711	9.877×10^{-15}
1.07 µm	0.15	0.2304	3,794,171.332	2.820×10^{-13}
9.83 µm	0.9	0.1198	9,293,783.761	1.058×10^{-12}
113.09 µm	4.5	0.04546	20,781,532.26	5.442×10^{-12}
180.69 µm	6.0	0. 03734	23,996,446.49	7.530×10^{-12}
233.00 µm	7.0	0.03353	25,919,124.56	9.710×10^{-12}
422.64 µm	10.0	0.02598	30,979,279.2	1.364×10^{-11}

***Table 1:** Summary table for each penetration depth. For detailed calculations, refer to the supplemental document [5][6][7].*

In the first part of this study, we explore the quality of the exfoliated lamina depending on the depth of implantation (the thickness of the lamina). To vary the thickness of the lamina, we will vary the speed of the protons (kinetic energy), calculated using Bethe's law (refer to supplemental). The table above provides corresponding proton speeds for each desired lamina thickness.

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Because not many proton implantation studies on Germanium studies have been conducted, we plan to vary the number of protons per beam, using a baseline of 2.3×10^{12} protons.

2.2 Proton writing Germanium

In addition to slicing germanium wafers, we wanted to explore applications in photolithography. Traditionally, the process involves using light to etch a pattern onto a silicon substrate. The precise control of the beam enables the fabrication of integrated circuits – a critical component of semiconductor electronics.

To accomplish this, we will use the 180.69 μm wafer as the substrate. Next, we will recalibrate the parameters of the proton beam such that the penetration depth is $0.003163\ cm$, in line with silicon writing which estimates 0.0048 cm [9].

Achieving optimum control of the set-up requires the use of a fast-scanning magnet system, provided by CERN [8]. Using 2.0 MeV as the energy of the proton, we can calculate the magnetic rigidity and the magnetic field (refer to supplemental). The values we find are well below the maximum values established by CERN's fast-scanning magnet system, enabling a swift integration into our own set-up (**Figure 1**).

III. What we hope to take away

By observing fascinating physics processes in action at CERN, we hope to uncover insight that will drive future research for physicists worldwide. After performing our experiment, we would reflect on the outcome and hopefully use this new knowledge to expand the use of germanium as semiconductors, contributing to the increased efficiency of electronics in various industries. We believe that particle physics can be an instrumental tool in combating issues of the world through cutting-edge technological advancements, and we are eager to be a part of this effort.

IV. Outreach

As TJ's Quantum Physics club, we direct our outreach efforts towards engaging local students with library lectures, performing demonstrations with optical equipment, and inviting guest professors to give speeches. At weekly club meetings, we update our members on recent scientific developments, imploring them to dive deeper into the physics behind new technologies. With the upcoming Techstravaganza event, our school's annual science symposium, we are excited to present a quantum physics booth showcasing our projects from this school year, along with our Beamline experimental design. Further increasing exposure, we want to create YouTube videos revealing our experiment logistics to interested viewers. If we are given the opportunity to perform our experiment, we will

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eagerly publicize our findings through videos, articles, and presentations, reaching diverse audiences of students, teachers, and professors and facilitating the spread of new particle physics knowledge.

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