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Reproducible, low-temperature growth of nanocrystals in an amorphous silicon film

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During Plasma-Enhanced Chemical Vapor Deposition (PECVD) crystal growth, an electric field between two charged plates dissociates a gas into a cloud of positive and negative ions called a plasma. The silicon ions descend to the silicon wafer and bond to the surface. Temperature is controlled and usually in the range of several hundred degrees celsius. Dispersed throughout the amorphous thin film are patches of crystalline structure that are nanometers in diameter.

The goal of this project was to vary temperature, gas flow, gas mixture, gas pressure, and power settings on the PECVD system at BYU so as to consistently produce silicon nanocrystals of 2-3 nanometers in diameter with a density of $10^{12}/\text{cm}^2$. It was expected that a temperature of 250 °C, 3 sccm silane flow, 140 sccm hydrogen flow, 1500 mTorr of pressure, and 20 Watts of power would produce the desired crystal formations. Temperature increase, silane flow decrease, hydrogen flow increase, pressure increase, and an increase in power on the electrode plates were expected to decrease crystal size and increase density.

To gain access to the Integrated Microelectronics Laboratory (IML) that houses the PECVD, I had to pass several tests covering the various acids and bases. I also had to be trained to use the PECVD system. After training, I waited some time for hydrogen to be installed; however, after reviewing the matter with Dr. Hawkins, we realized that hydrogen was not a factor determining the size or density of the crystals. As a note concerning gas measurement: gas lines and flow meters are attached to the PECVD in such a way that gas flow is measured in percent of total capacity, not sccm.

During the summer months I joined a group of students and faculty who were conducting research in the IML. My responsibilities in that group included assisting with the web page for the IML and creating the specific page for a mask aligner in the cleanroom. Thus, as part of my ORCA project, I became familiar with more of the IML and also met other students and faculty working on similar projects.

Once research began, I found some difficulty in analyzing my experimentation. I had access to a Scanning Electron Microscope (SEM), but its older technology made finding crystalline structure literally like finding a needle in a static-filled image of a haystack. Even though hours spent on the SEM produced few results, my research would have been impossible without its capabilities.

Following a pre-planned variation of parameters, I conducted several sets of experiments. After each set, I scheduled a time to examine them under the SEM with the assistance of Elizabeth Despain, a student qualified to use the microscope. My research revealed a slightly different model than I had anticipated. My previous research pointed to higher pressure and higher power giving decreased crystal size and increased density; however, the results of my research suggest that higher power yields fast, concentrated, spot growth; low power resulted in slower, smaller, more uniform crystal growth.

As shown in Figures 1 and 2, the settings I predicted would create the ideal crystal did in fact diameter, it is about as small as is possible to see with the SEM we used. Figure 2 shows at somewhat lower resolution a splotchy grey white area on the wafer, which was very similar to

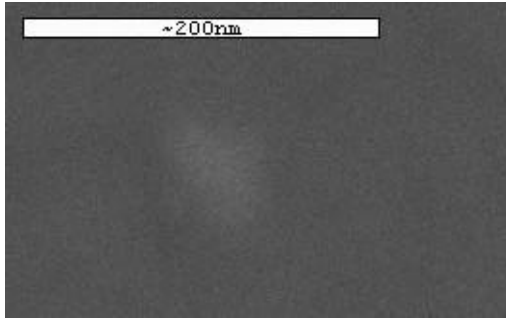


Fig. 1: SEM image of a wafer with potential this sample were 20 W power, 1000 mTorr pressure, 250 °C temperature, 20 minutes time.

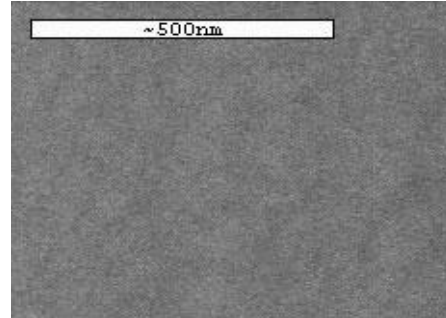


Fig. 2: SEM image at slightly lower resolution showing the uniformity of the proposed crystal structure (splotchy grey/white areas) from low power/high pressure settings.

Figure 3 shows a much larger proposed crystal formation. The sample in Figure 3 was grown at considerably higher power and lower pressure than the samples in Figures 1 and 2.

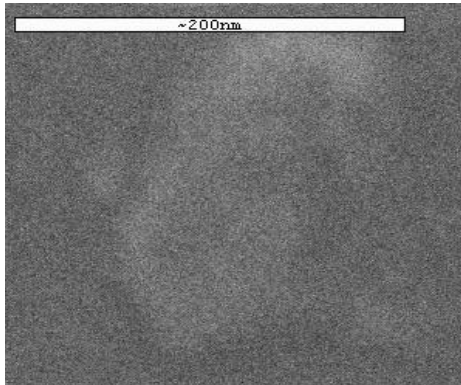


Fig. 3: SEM image of a wafer with potential crystal formations (the lighter regions). Settings for this sample were 200 W power, 200 mTorr pressure, 250 °C temperature, 30 minutes time.

The samples shown in the figures displayed here demonstrate that higher power and lower pressure tend to grow crystals faster and in greater concentration in some regions of the wafer, while lower power and higher pressure produce uniformly smaller crystals. A more rigorous treatment of the topic of silicon nanocrystals would require a microscope with higher resolution and greater clarity.

With the opportunity to carry out my proposal, I found great occasion to associate with dedicated faculty and students, take part in real research, and explore an emerging world of physics that would have been inaccessible without such a grant. Although my research covered just a miniscule portion of a complete study of silicon crystals, it is yet a step further into the world of education, and a valuable learning experience on my part.