Synthesis of Advanced Optical Interconnect devices using reactive ion etching and plasma enhanced chemical vapor deposition processes.

This paper addresses the use of reactive ion etching (RIE) and plasma enhanced chemical vapor deposition (PECVD) processes to fabricate Advanced Optical Interconnect (AOI) technology devices. Interconnect technology, which bridges individual transistors on a computer chip, currently employs metal conductors separated by dielectric materials. AOI technology includes nano-optical sources, detectors, and waveguides, as well as on-chip devices (i.e. sub-200 nm scale and smaller). The main concentration of this paper is on the synthesis of optical test structures using RIE. Two different types of thin films were etched–Silicon, Si (deposited via PECVD onto Barium Fluoride–BaF_2–substrates using a Silane (SiH_4)/Hydrogen (H_2) plasma) and Cadmium Telluride (CdTe)–both patterned with photoresist. For the first part of the experiment, Si thin films were etched with Sulfur Hexafluoride (SF_6) and a passivating gas–i.e. Tetrafluoroethane, $C_2H_2F_4$–using the Time Multiplexed Deep Etching (TMDE) technique. The etching of the CdTe surfaces was achieved with a mixture of gasses–i.e. Methane (CH_4), Hydrogen (H_2), and Argon (Ar)–by way of an RIE process. Silicon (Si) was then deposited preferentially into the holes, using PECVD. An optical spectrometer was used in both the etching and deposition processes to correlate plasma conditions with processing results.

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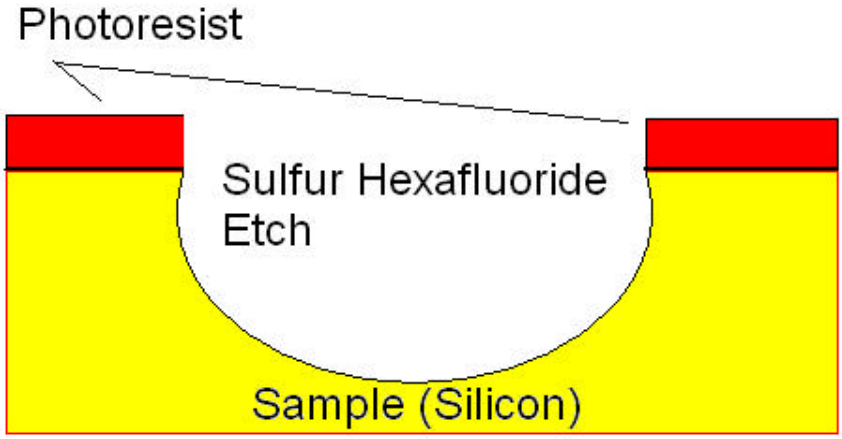
•Advanced Optical Interconnect (AOI) test structures were fabricated using inductively coupled plasmas (ICP's).
•The "interconnect" on a computer chip are the "wires" that connect individual transistors.
•AOI devices are envisioned to replace conventional interconnect approaches (copper/low-k materials).
•Reactive ion etching (RIE) of Silicon (Si) and Cadmium Telluride (CdTe) thin films was explored.
•Plasma enhanced chemical vapor deposition (PECVD) of Silicon was also employed.
•Processes were monitored using optical spectrometry, so that plasma conditions could be correlated to processing results.

What is reactive ion etching (RIE)?

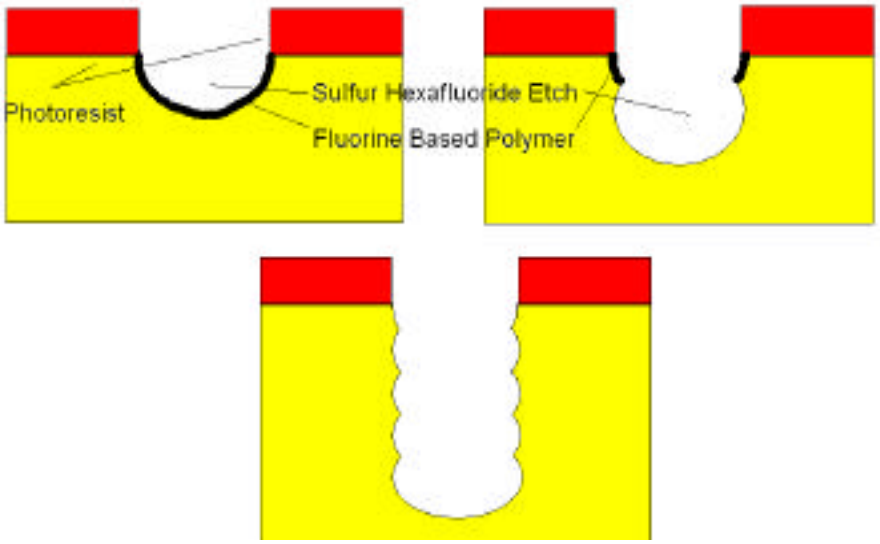
•RIE is the use of a gas in its plasma phase to undergo chemical reactions with the substrate in its solid phase to create volatile products.
•When a sample of, for example, Silicon, is patterned with photoresist and put into a chamber with a plasma–Sulfur Hexafluoride, for example–RIE occurs.
•The activated gas (and plasma) reacts with the Silicon atoms to form one of several volatile products.



•This is an “isotropic” etch profile. Sulfur Hexafluoride does not etch directionaly, but industry requires trenches with relatively flat sides.

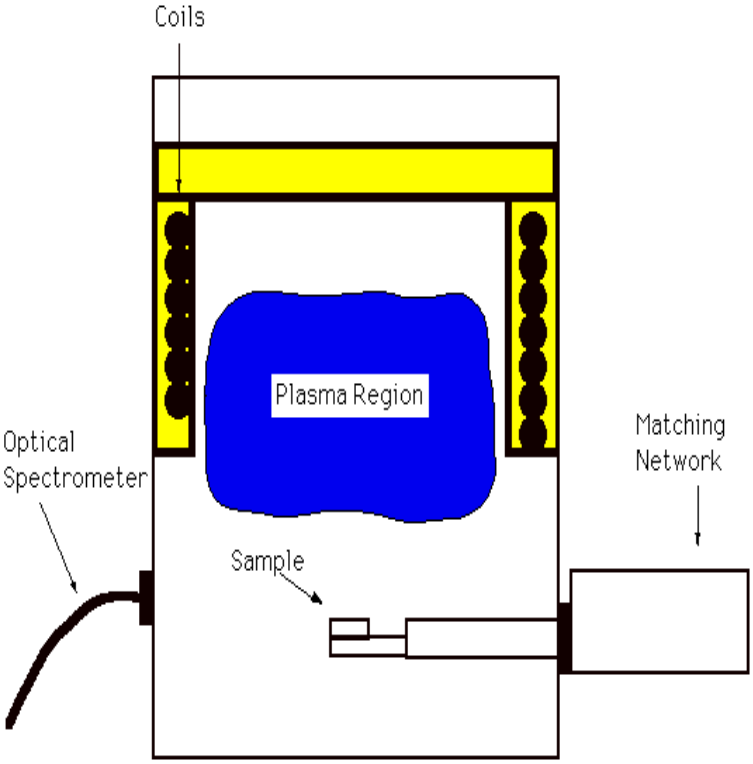
The Time Multiplexed Deep Etching (TMDE) process.

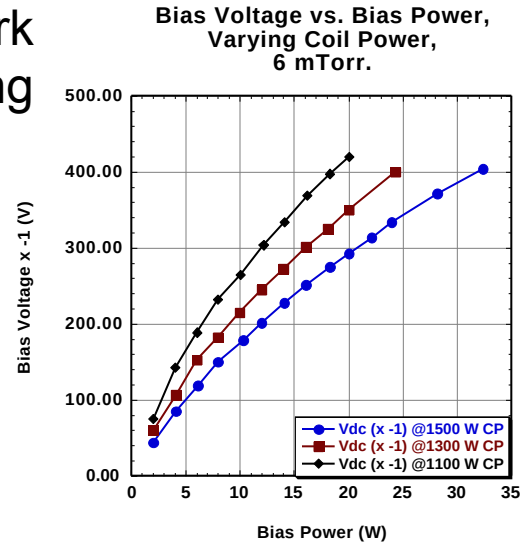
•This process relies on a few simple facts–first, Sulfur Hexafluoride etches isotropically.
•Second, a Fluoro-Carbon gas in its plasma form will deposit a Fluorine based polymer.
•Once the first etch step has been completed, the polymer is deposited (top, left).
•The etching gas (like Sulfur Hexafluoride) is reintroduced into the chamber, and begins to etch the bottom of the trench (top, right).
•This process is continued until the desired depth is achieved.
•The polymer is removed so that the final product resembles the bottom, middle figure.

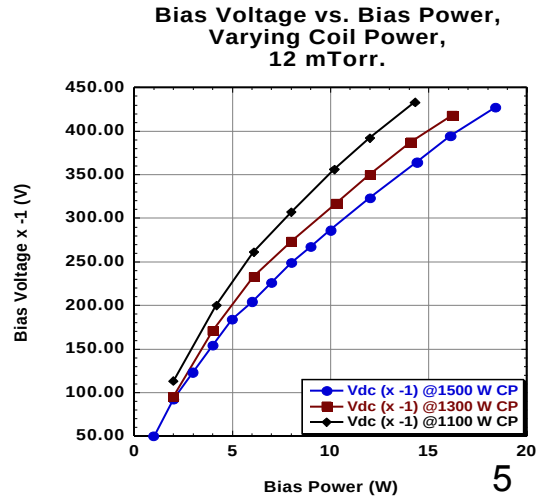


Note the “scallops”, or “ripples” on the side walls of the trench. These can be kept to a trivial size–that is, they are so small they do not effect the performance of the device.

Power Figures for Matching Network (SF_6 Plasma), right, and Etching Chamber Schematic. below.

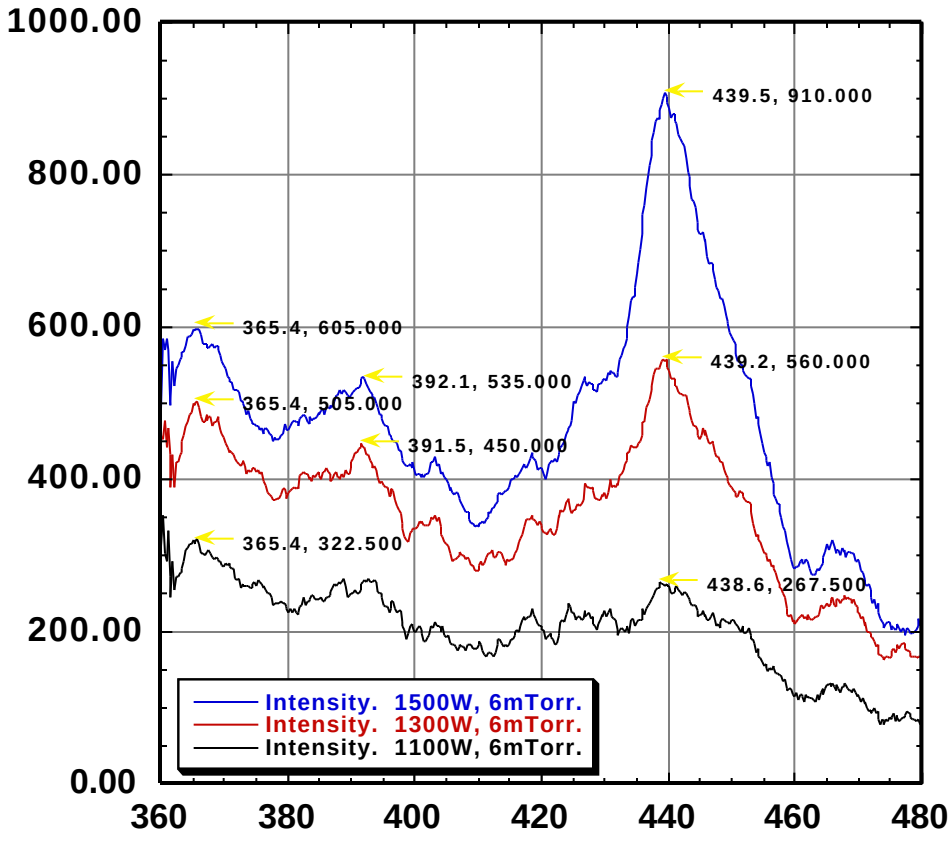






Spectrometer Panel

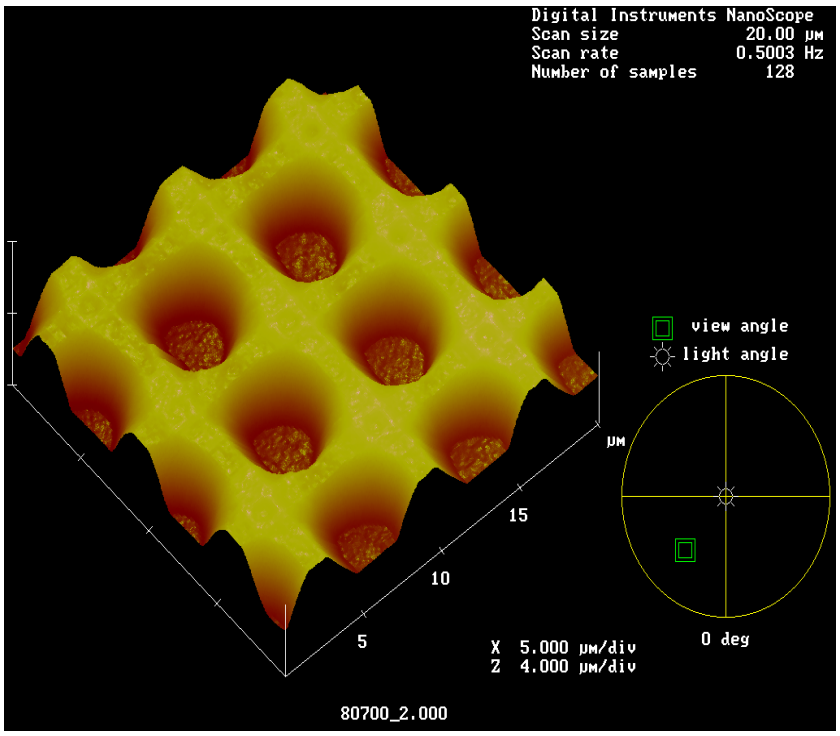
Spectra of SF_6 Under Constant Pressure, Varying Coil Power, and 0 Volts DC Bias.

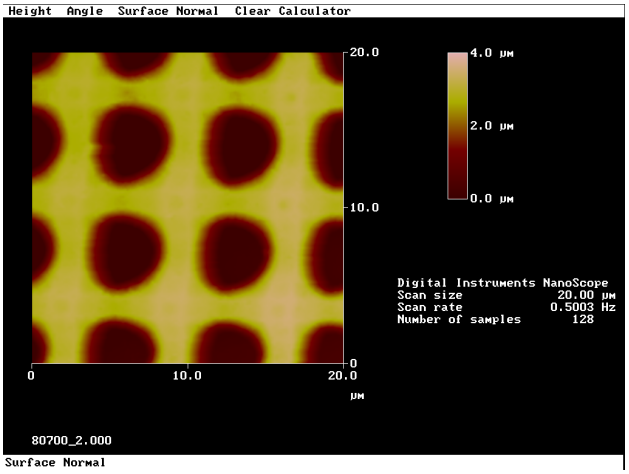


The peaks, left to right, have been identified as Sulfur Fluoride, Silicon Difluoride, and Silicon Fluoride. The peak at roughly 440 nm (SiF) is usually a rather unintense peak. Quartz walls, constituting about 120 times the surface area of the wafer, make up the inner surfaces of the chamber, so the rather intense SiF peak is due to the etching of the inside of the quartz.

Atomic Force Microscope (AFM) Images of Second Si/BaF_2 Sample : Hole Pattern.

These images, taken by Dr. John T. Simpson,give a good idea of what the sample looks like on the micron scale. The left sample shows a fairly sloped profile–this should be taken with a grain of salt, however, because the tip of the AFM limits its ability to measure sharp changes in altitude–the results may be better than the picture indicates. SEM micrographs for all AFM images are planned.



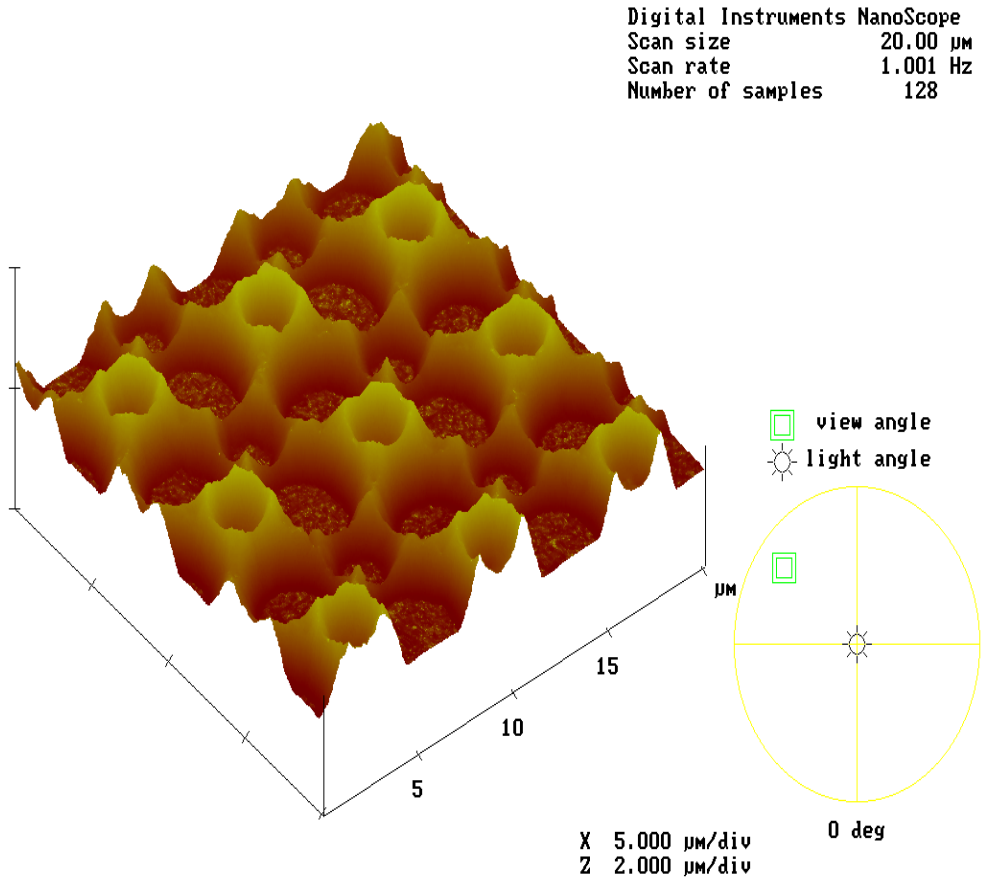


Above : A two dimensional, “bird's eye” view of the sample.

Left : A three dimensional view of the sample.

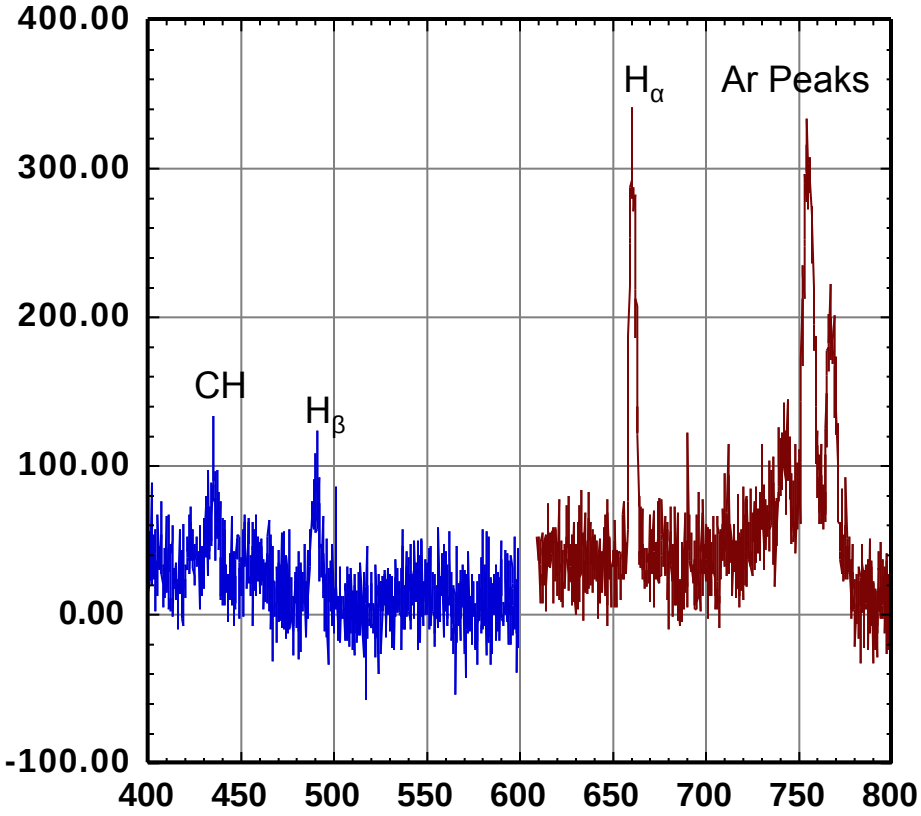
Texture Waffle

AFM Image of Second Si/BaF_2 Sample : Post Pattern.



This image of the sample is not as aesthetically pleasing, but does give a great deal of information : this image proves that the photoresist was etched all the way through, and that the aggressive chemistry involved here did etch the silicon through to the BaF_2 wafer.

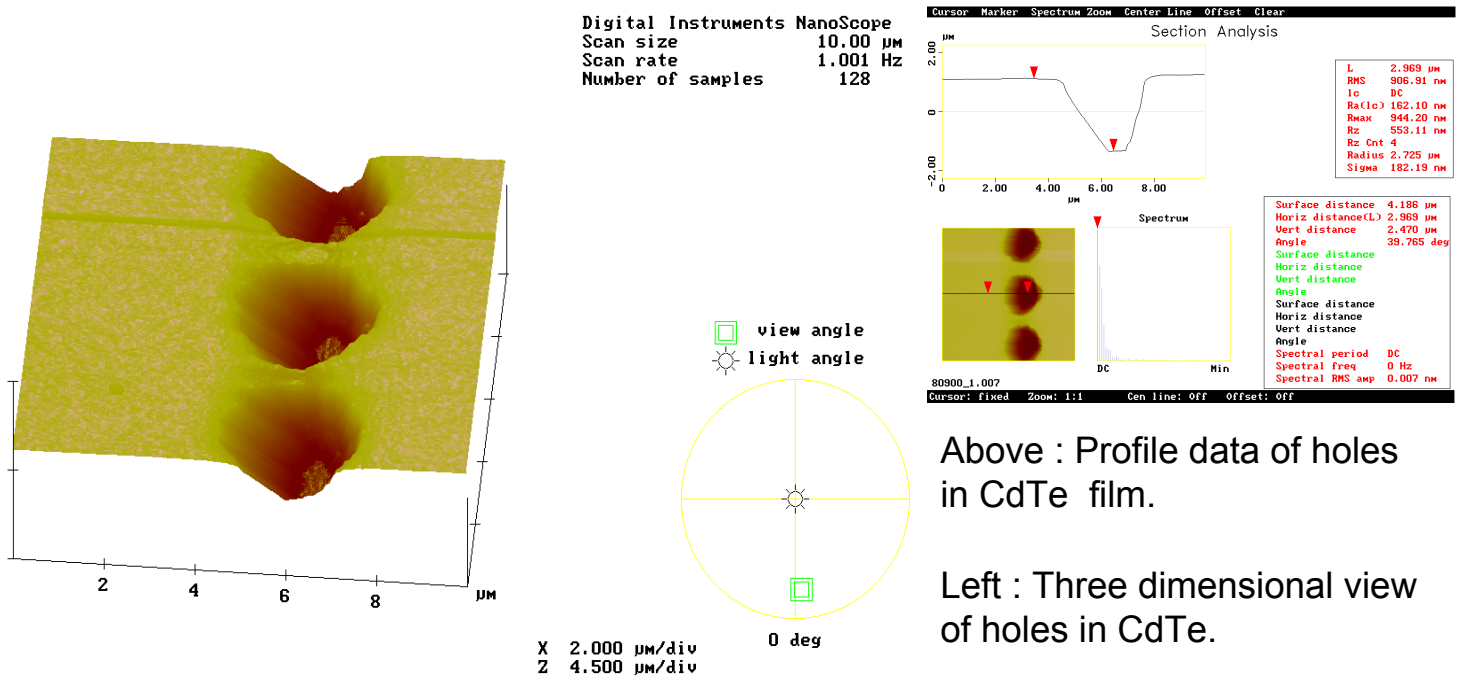
Spectrum of CdTe Etch Plasma : $CH_4/H_2/Ar$. 1500 W, 10 mTorr.



The gases used in the CdTe RIE process emit lines at 435.0 nm, 489.4 nm, 660.2 nm, 754.6 nm, and 766.6 nm. Argon has its typically intense lines at the end of the spectrum (754.6 nm and 766.6 nm), and Hydrogen's α and β lines are rather intense (660.2 nm and 489.4 nm). The peak at the far left of the spectrum has been identified as CH (431.0 nm).

AFM Image of CdTe Pattern.

The depths of these holes was calculated to be on the order of 2.5 µm, but the thickness of the CdTe film was on the order of 200 nm. This means that the CdTe etch rate was higher than previously reported, and that the silicon crystal on which the CdTe had been deposited was etched to some degree. This test structure is now ready for the PECVD process, in which silicon will be deposited into the holes.

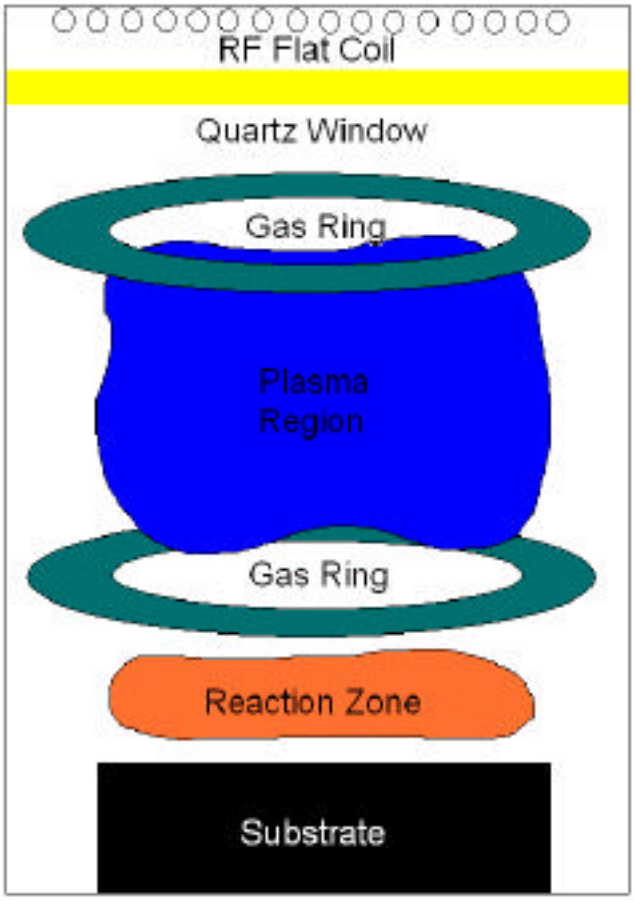


Above : Profile data of holes in CdTe film.

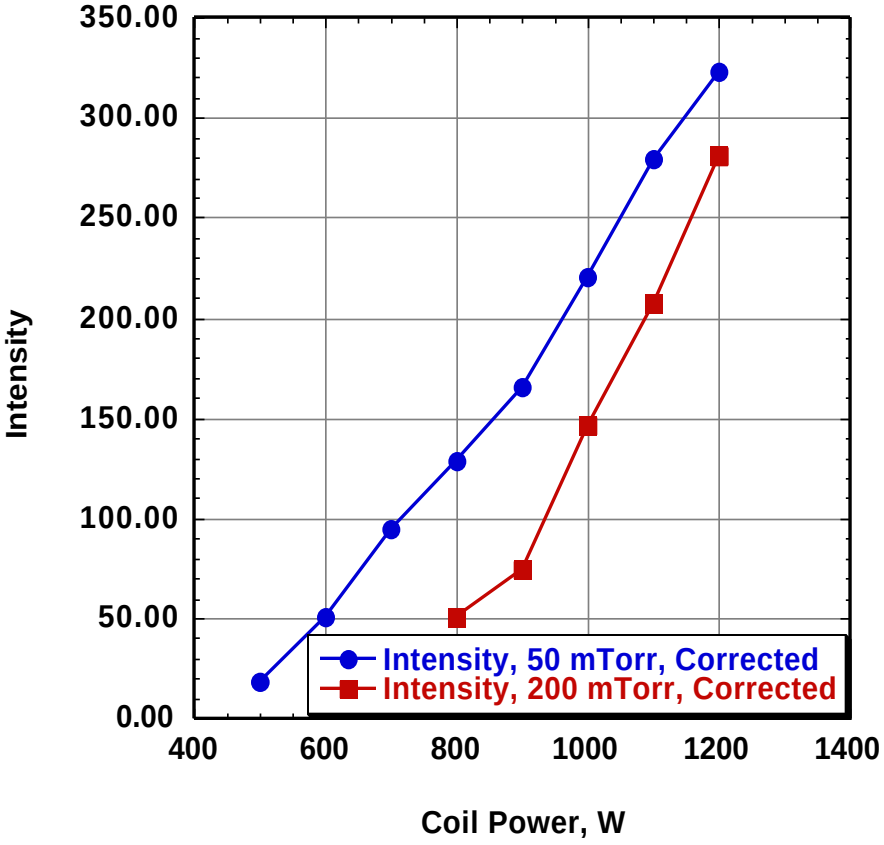
Left : Three dimensional view of holes in CdTe.

Plasma Enhanced Chemical Vapor Deposition

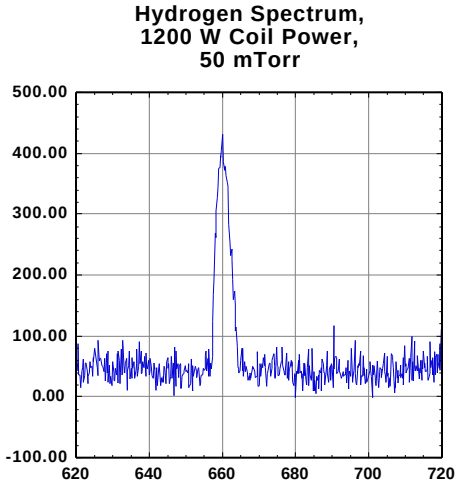
•Plasma Enhanced Chemical Vapor Deposition (PECVD) is a more efficient approach to traditional Chemical Vapor Deposition (CVD).
•PECVD involves one or more plasmas, as well as a deposition gas reacting to form non-volatile products, which will be deposited onto the substrate.
•The excited gas molecules diffuse from the Plasma Region into the Reaction Zone, where the multiple species interact.
•PECVD is faster than traditional CVD, and the temperatures involved are not as extreme. When Silicon was deposited onto BaF_2 wafers, temperatures of about 400°C were used and deposition rates were on the order of 900 Å/min.



Optical Emissions : Ha Lines in the Deposition Process. Intensity vs. Coil Power.



H_α lines were monitored and correlated to coil power. Below is a sample of the H_2 spectrum. Note the intense H_α line at about 656.2 nm.



Conclusions.

•Advanced Optical Interconnect (AOI) test structures were fabricated using reactive ion etching (RIE) and plasma enhanced chemical vapor deposition (PECVD).
•The Time Modulated Deep Etching (TMDE) process was successfully employed to gain a good deal of anisotropic etching of Silicon thin films on BaF_2 wafers.
•Results of several studies were reproduced successfully in the RIE process for CdTe.
•Future research should address the need for a passivating gas when etching thin Si films while using high bias voltages.

Acknowledgments.

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