Fabrication of Single Crystal Silicon Photonic Crystals

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Abstract:

Photonic crystals are periodic arrangements of dielectric materials, in our case a two-dimensional array of holes etched into a silicon substrate, that have special optical properties. We fabricated these photonic crystals out of single crystal silicon using the GOPHER process, which stands for the Generation Of PHotonic Elements by RIE (reactive ion etching) [1]. These photonic crystals have been shown to have high reflectance over a broad wavelength range and therefore are useful as broadband mirrors. They also are made from single crystal silicon so the effects of silicon migration to improve the performance of the photonic crystals can be tested.

Introduction:

Photonic crystals made from single crystal silicon can be fabricated to have high reflectivity over a large wavelength range and therefore be very useful as broadband mirrors [2]. Photonic crystals or PCs are periodic arrangements of dielectric materials that, because of their structure, have interesting optical properties. Photonic crystals can be fabricated that are one, two or three dimensional.

An example of a one dimensional photonic crystal is a Distributed Bragg Reflector or DBR. A DBR is a layered structure that has films of alternating high and low indexes of refraction and very precise thicknesses. Two dimensional photonic crystals have a periodic structure in two dimensions. The photonic crystal fabricated using the GOPHER process is an array of holes etched out of a single crystal silicon substrate. The benefits of using the GOPHER process over other methods of fabrication include that the final photonic crystal is stress free and fabricated from a silicon wafer, which is inexpensive when compared to silicon-on-insulator (SOI) substrates. Another benefit of the GOPHER process is that the finished photonic crystals are single crystal silicon. This is important because silicon migration experiments can be performed on single crystal silicon structures.

Procedure:

To fabricate these photonic crystals using the GOPHER process, we started by thermally oxidizing the wafer. The wafer was then coated with photoresist, the photoresist patterned and developed, and the pattern was etched through the oxide to create a mask for the etching steps. After the resist was stripped, holes were etched into the substrate with the first directional silicon etch, then the sidewalls were oxidized, and the oxide on the bottom of the holes was etched. The second directional silicon etch then deepened the holes, and an isotropic silicon etch undercut the photonic crystal. An SEM image of the finished GOPHER photonic crystals that were fabricated is shown in Figure 1.

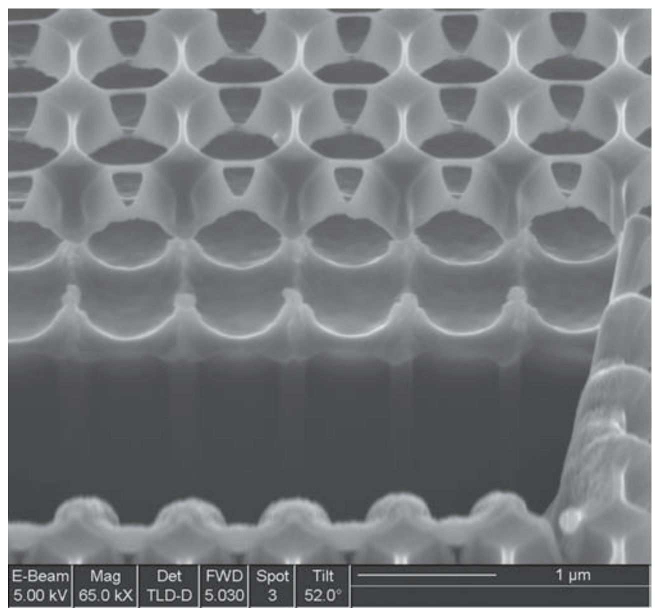

Figure 1: SEM image of the finished GOPHER photonic crystal.

After fabrication, the reflectivity of these photonic crystals were tested using a broadband light source and an optical spectrum analyzer. Light from the broadband source was focused onto the photonic crystal and the reflected light was fed into the optical spectrum analyzer. The reflectivity was obtained by comparing this data to a measurement of the reflectance of bare silicon which is known to be 31% in the frequency range that was measured.

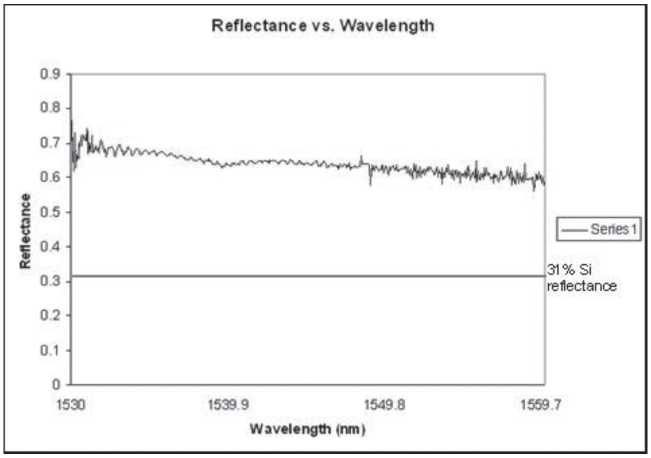

Figure 2: Plot of reflectance vs. wavelength for the fabricated photonic crystal. Line shows the 31% reflectivity of bare Si.

Results and Discussion:

The fabricated photonic crystals performed as expected in the tests. The reflectivity was above 60% over the range that we measured as shown in Figure 2. Wavelength regions with higher reflectivity could have been out of the wavelength range that we measured, but due to a limited range broadband light source, we were unable to verify this. After looking at the devices in an SEM we noticed that the holes that made up the periodic structure of the photonic crystal were longer in one direction than the other. Although we did not see any effects from this, further polarization testing on these photonic crystals could show a polarization effect from this difference.

Future Work:

The photonic crystals that we fabricated are going to be used to test the effects of the migration of single crystal silicon on the optical performance of the photonic crystals. Silicon migration can be used to reflow single crystal silicon structures and cause them to go to a low surface energy state. This can be done by annealing at high temperatures in a non-reactive ambient such as hydrogen. This improves the efficiency of the photonic crystals by smoothing out sharp edges and rough surfaces from etching. Figure 3 shows a GOPHER PC before and after annealing, and after the structure was annealed almost all of the rough edges have been smoothed out which will decrease the amount of light that is scattered. The photonic crystals that we fabricated will be used to further test this process and try to optimize its use for these photonic crystals.

Summary and Conclusions:

Photonic crystals are periodic arrangements of dielectric materials fabricated to have interesting optical properties. The photonic crystals that we fabricated and tested had high broadband reflectivity which is useful for broadband mirror applications. The GOPHER process was used to fabricate these crystals using reactive ion etching to etch holes into a silicon substrate. The resultant photonic crystal was stress free and composed of single crystal silicon.

The photonic crystals that we successfully fabricated this summer were tested and shown to have the high reflectivity characteristics that we were striving for. In the future the PCs that we have made will be used to further test the hydrogen annealing process to improve the performance of the phonic crystals.

Acknowledgements:

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References:

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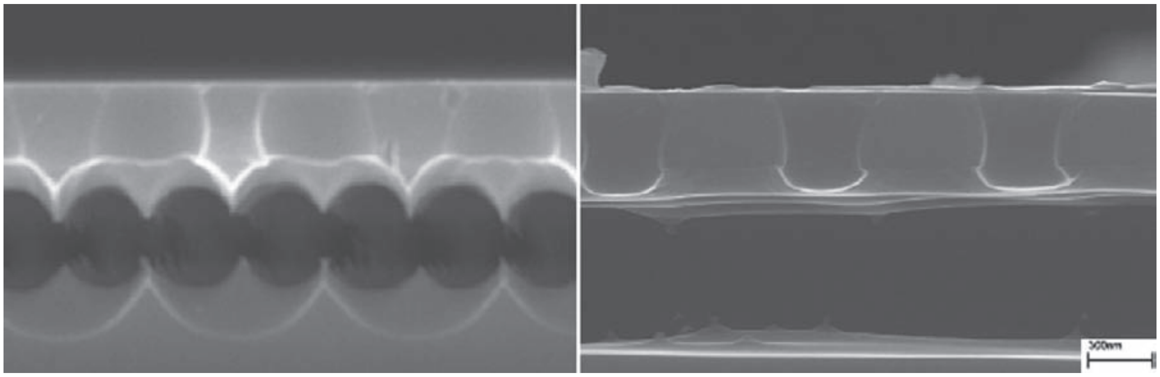

Figure 3: An GOPHER photonic crystal before annealing (left) and after annealing (right) [3].