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Larger Scale Fabrication of Nanometer to Micron Sized Periodic Structures in 2D and 3D: Approaches and Trends

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Fabrication of periodic structures for photonic or phononic wavelength interaction and manipulation at the small scale (<100um x 100 um) in planar dimensions using a variety of materials and techniques has been documented in the literature. Often structures are conceived and built with only a single device needing to be made. Some applications require that structures be fabricated in three dimensions or with multiple layers placing additional constraints on the fabricator. If a structure proves to be useful and a demand to have it appears, the researcher is often asked, "Can you make more of it?" The challenge to manufacture larger, better structures, and more of them is not new in the history of product innovation and manufacture. However, the combination of requirements for accurate microscopic dimensional control over large spatial scale needed to make useful devices requires both out of the box thinking to manufacture them and familiarity and the ability to adapt tried and true scaling techniques.

Human ingenuity and desire for efficiency has used the "stamp" for thousands of years to impart a repeated pattern into materials that served, speed, ease of use, and functionality requirements. Signet rings or "seals" were used with waxes or inks to authenticate the earliest hand written documents and are still in use today. (1) The method of placing multiple patterns or individual stamps next to each other surfaced in China in the early 11th century (2). Combining the patterns with a proper substrate material (paper) made communication easier and faster. Researchers in photonic crystal fabrication have leveraged the established stamping technique to deliver fabrication of large area 3D photonic crystal designs. Instead of clay tablets, engineered siloxanes have allowed for durable and re-usable stamps that are able to replicate the molded features at the nanometer scale. The stamping technique can be enhanced by combining with well established optical principles to generate three dimensional periodic structures. Further leveraging sophisticated modeling, semiconductor processes and engineered materials enables fabrication of large area, three dimensional periodic structures with submicron features. Figure 1a is a photograph of a large area silicone based stamp used to imprint phase masks into the surface of photo resists. Figure 1b is a photograph showing the diffraction pattern created by the phase mask using collimated light (3).

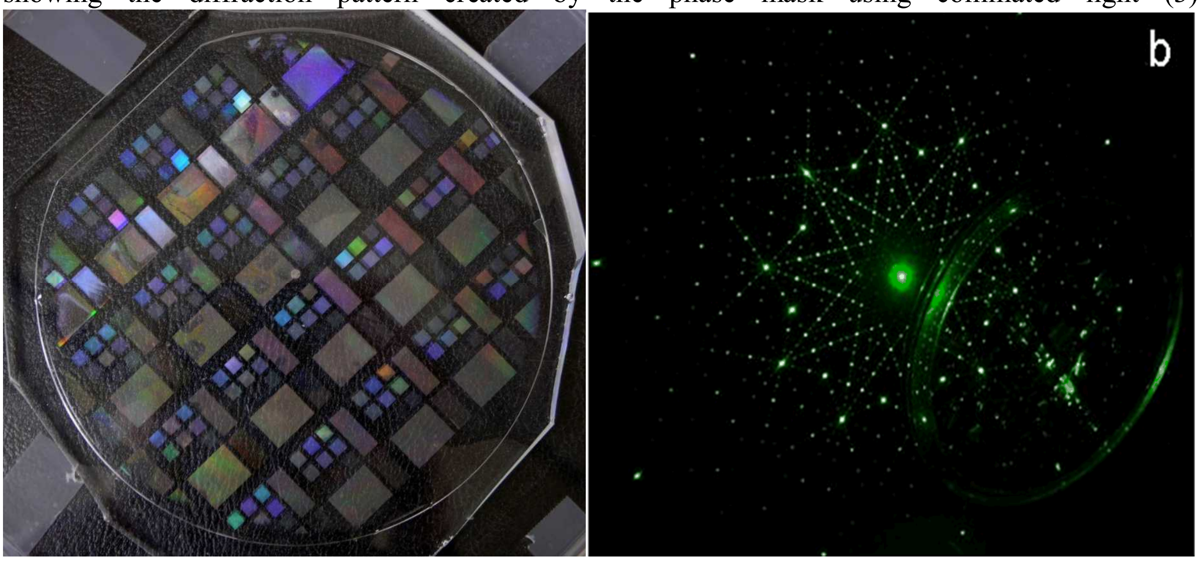

Figure 1. a.) 150mm diameter stamp master for proximity nano patterning of quasi crystal pattern. b.) diffraction pattern generated using an engineered phase mask.

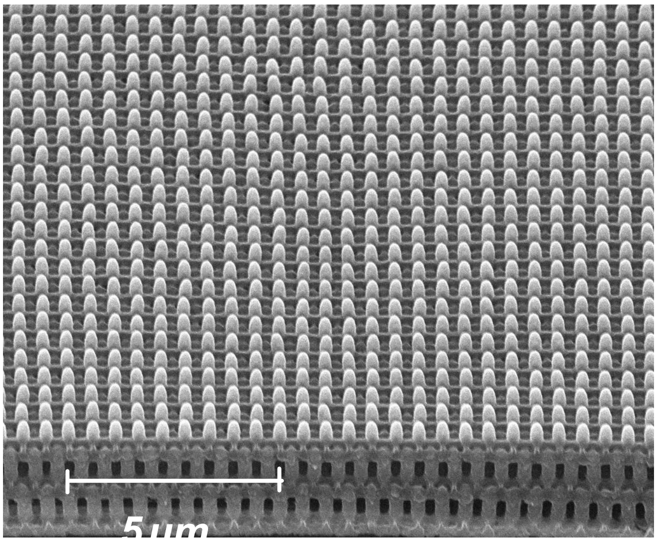

Figure 2. Cross section SEM of a resist structure generated with a stamped phase mask on the surface of the resist.

Collimated light used for exposure combined with the surface relief generated by the stamp creates constructive and destructive interference patterns in three dimensions. Figure 2 contains a cross sectional scanning electron micrograph of exposed and developed photoresist using an optical phase mask generated with a stamped surface and optical interference. Note the periodic nature in all three dimensions.

Many materials that are suitable for optoelectronics and CMOS device manufacturing are also finding uses in the phononics area. Lithium niobate has been used extensively in optoelectronic fabrication due to its desirable optical properties. It is particularly challenging to process using conventional CMOS process techniques as it is both pyroelectric and piezoelectric. Processing limitations can impact the usefulness and implementation of these materials.

Large scale fabrication of these types nanometer sized periodic structures requires an integrated approach. In this presentation I will review other scaling approaches to making large area phononic or photonic crystals in 2D and 3D such as direct write and self assembly. In addition, I will touch on the necessary infrastructure required to develop these techniques including modeling, design, and material considerations appropriate for the various methods. Lastly, I will discuss future trends of the technology.

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