Fabricating Advanced Microsystems with Conformable-Contact Photolithography

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Conformable-Contact Photolithography (CCP) has been developed at MIT as a low-cost method of replicating sub-100-nm features. The primary goal of this program is to develop an integrated microphotomultiplier, a non-silicon-based device that may offer ultrasensitive and ultrafast light detection in a several-micron-sized integrated package. Also during this program, patterning experiments have been carried out to assess the usefulness of this technology for other applications in the area of microscale device fabrication. By utilizing near-field optical effects in these experiments, features smaller than 50 nm have been created, for a restricted set of experiments.

For CCP, pattern replication is achieved after bringing a thin conformable mask with a patterned attenuator into intimate contact with a resist-coated substrate, and exposing the entire area with 220 nm radiation from an arc lamp. This technique has been used to pattern fine features over areas as large as 30 cm2 in a single exposure. Additionally, we have shown that in-plane distortions of the mask are as small as 55 nm over a 4 cm2 area, and that multi-level alignment , with overlay accuracies well below one micron, can be achieved readily.

The primary objective of this research program is to demonstrate a novel integrated microphotomultiplier. A preliminary design of this device is complete and requires three mask levels. Each level will be patterned via CCP using a custom contact nano-aligner designed and assembled at MIT. The first set of masks have been fabricated, and patterning with the first-level mask has begun. The prototype will be fabricated on an oxide substrate, and combines photomultiplier and microchannelplate amplification technology. The basic design is depicted in Figure 22.

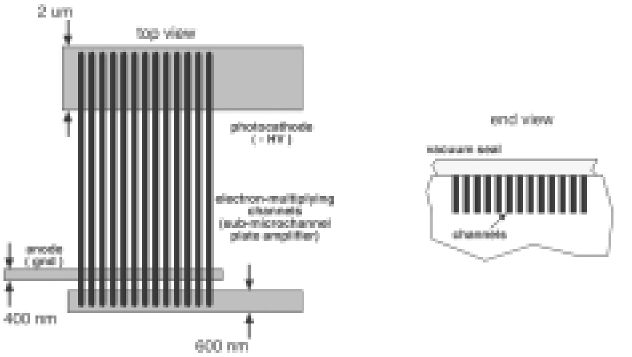

Fig.22: The basic design of the integrated micro-photomulitplier is shown. Electrons are created at the photocathode, and accelerated down electron-amplifying channels. The channel widths are about 80 nm and the length varies from 2.4 μm to 19.2 μm for different devices. Channels with straight and zigzag (Fig. 2) geometry have been fabricated.

There are two critical components to the integrated microphotomultiplier: the photocathode and nanometer-scale electron-amplifying channels. The photocathode converts incoming photons to electrons, which are accelerated down the channels, generating secondary electrons in the manner of an avalanche. Amplification within the channels is exponentially sensitive to the aspect ratio of the channels. Channels with high aspect ratios, and varying geometry, can be obtained readily via in-plane microfabrication. An example of zigzag amplifying channels, fabricated via CCP, is shown in Figure 23. These channels were fabricated in oxide.

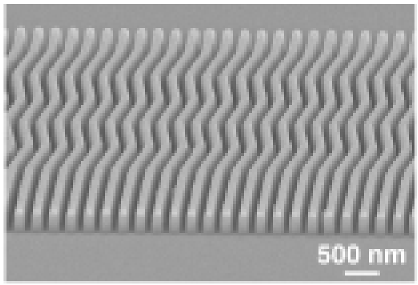

Fig.23: These zigzag channels, etched in oxide, and planned for use in an integrated micro-photomultiplier, resulted from the first level of conformable-contact photolithography. The completed device requires three levels of lithography. It does not require crystalline semiconductors, and is expected to have near single-photon detection sensitivity.

In the second level of lithography, the photocathode will be patterned at one end of the channels. The channels will then be sealed. Electrical contacts will be opened in the third level of lithography. We look forward to preliminary testing of the device in the coming year.

Several patterning experiments were carried out to evaluate the feasibility of using CCP for other microfabrication applications. Numerical simulations of contact photolithography were also carried out to assist in these experiments. For the simulations, the finite-difference time-domain field solver TEMPEST, available over the internet at http://cuervo.eecs.berkeley.edu/Volcano/, was used. In Figure 24, results of a simulation, 3(b), and CCP patterning experiment, 3(c) show good agreement. The diameter of the aperture used for the model and experiment was 320 nm. A small dark spot appears, ala Fresnel, at the hole center. This spot can be transferred into resist forming a sub-50-nm diameter post at the center of the hole, as shown in 3(c). This feature may be useful for the fabrication of electron field emitting devices. In similar experiments, narrow lines could be patterned at the center of long rectangular apertures, forming sub-80-nm-wide channels, and a grid of 60-nm-diameter posts was formed within a 1um x 1.5um rectangular aperture. Additionally, it was shown that CCP can be used to pattern circular grating structures, Figure 25(a), and a dense triangular lattice of holes, Figure 25(b). These suggest the applicability of conformable-contact photolithography for patterning diffractive optical elements.

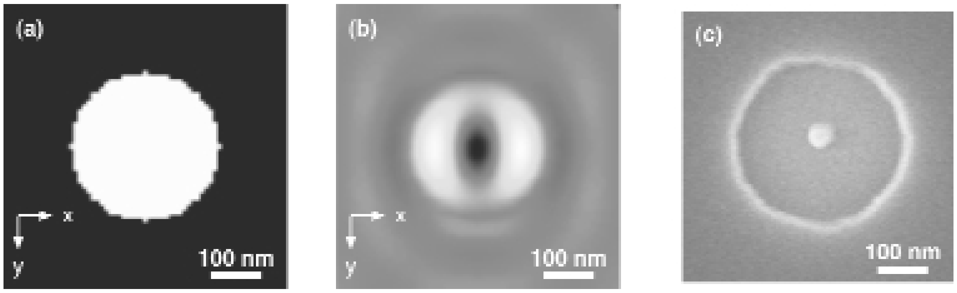

Fig. 24: The aperture model (a) was used in a finite-difference time-domain code, TEMPEST, to simulate the transmitted optical field shown in (b). The polarized excitation field, 220 nm wavelength, was calculated 20 nm beyond the aperture. An SEM image of the resulting printed pattern is shown in (c).

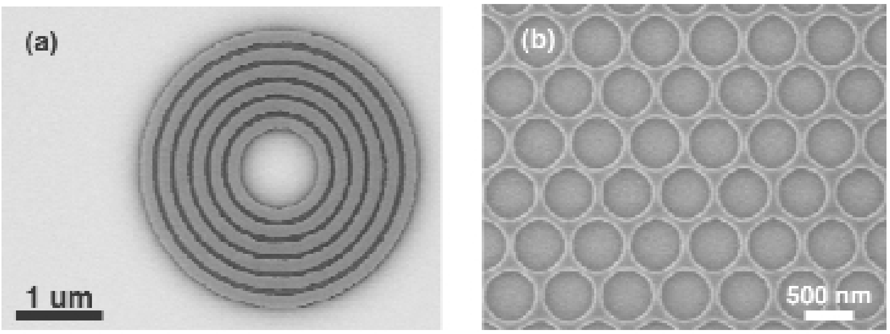

Fig. 25: Circular gratings of 200 nm pitch and a triangular lattice were patterned via conformable-contact photolithography. These structures show the technique's potential for fabricating integrated diffractive-optical elements.