Lloyd's Mirror Interferometer Using a Single-Mode Fiber Spatial Filter

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Laser interference lithography (LIL) is a well-established method to produce periodic nano-scale patterns used in a variety of research applications. The Lloyd's mirror interferometer configuration is one of the easiest to build and use. A single beam illuminates the sample directly from one direction, and by reflection from the Lloyd's mirror from the opposite direction. One major advantage of a Lloyd's mirror interferometer is that it requires only a single expanded beam. However, in our experience we have found that lasers can sometimes create issues with the quality of the beam shape and the pointing stability. Even with conventional spatial filters, these can have a serious impact on the quality and stability of an LIL exposure system. Depending on the diameter of the spatial filter pinhole, the laser beam shape directly affects the intensity pattern on the sample, and the pointing stability can cause the position of the apparent angle of the beam to shift, degrading or destroying the exposed pattern in the resist.

An alternative spatial filter based on a UV single-mode fiber (SMF) has the potential to remove these effects. The use of SMFs as spatial filters has been extensively studied in the past for other applications including astronomical visible and UV interferometry, microscopy, ellipsometry, and optical disc recording. SMFs are recognized as equal or superior to conventional pinhole-based spatial filters. In the past, the use of an SMF has been described for laser beam transport and expansion in both interference lithography and holographic photography. However, in both cases multiple beams from multiple fibers were used. In both cases sophisticated phase-detection and locking systems were required to compensate for the drift of the relative phase difference between the fibers.

Earlier SMF LIL work used a visible wavelength laser at 457.9 nm. The possibility of working at 325 nm allows access to significantly smaller period patterns and higher resolution photoresists. A polarization-maintaining (PM) fiber was previously used to maintain linear polarization. However, the output end of the fiber had to be mechanically rotated to adjust the polarization direction of the output. The use of non-PM fiber opens the possibility of rotating the output polarization by adjusting the polarization at the input end of the fiber, leaving the output end of the fiber untouched. Finally, if a single SMF is used in combination with a Lloyd's mirror interferometer, there would be no need for multi-fiber phase locking.

In this paper, we report the use of an SMF spatial filter as the source of a well-filtered, expanding beam together with a Lloyd's mirror interferometer. Because a Lloyd's mirror interferometer requires only a single beam, no phase locking is required. By using an SMF as the spatial filter, the output beam remains fixed in shape, position, and direction no matter how poorly formed the input beam or how it moves. Spatial noise will not couple to the SMF; instead, it dissipates into the cladding and jacket. Because the SMF is flexible, it can be used to conveniently route the beam to any desired position and direction. This eliminates the need for careful positioning and alignment of any beam transport mirrors.

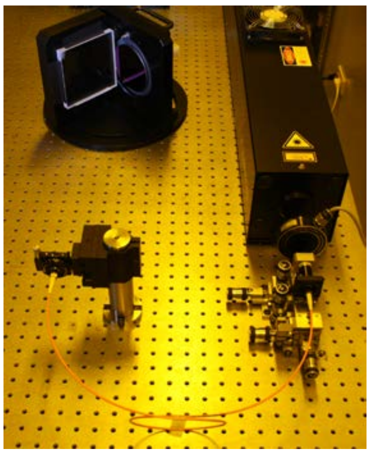

Figure 1: An illustration of the use of a single-mode fiber (SMF) as a beam transport system and spatial filter. The expanding beam from the fiber output (left side of photograph) illuminates the square Lloyd's mirror and round sample chuck on the left and right sides of the Lloyd's mirror mount, respectively. Note, only the major components of the system are shown, and the mount and HeCd lasers have been moved closer to consolidate the photographed area.

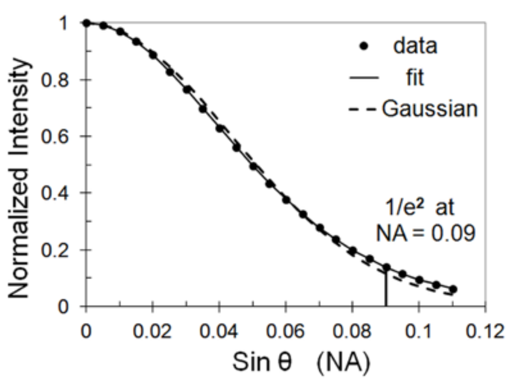

Figure 2. Radial distribution of the far-field intensity pattern from the fiber. Circles: measured data, Solid line: calculated far-field radiation from an LP01 mode of a step-index SMF that has been fit to the data. Intensity falls to   at   (the fiber NA). A Gaussian fit to the same data is also shown as a dashed line for comparison.

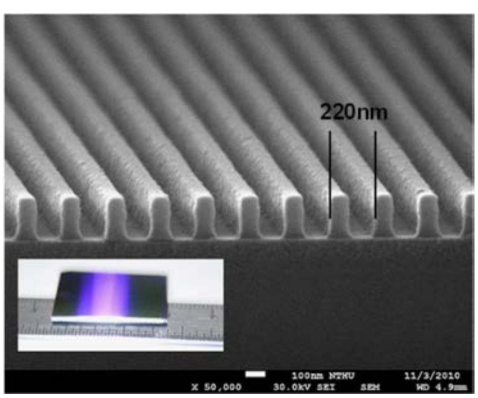

Figure. 3. Field emission SEM image of an exposed photoresist sample with a period of 220 nm. Inset: photograph of the same sample. The violet light seen reflected in the sample is back-diffraction of a white LED pen light by the photoresist grating.