Enlarging grating areas using multiple exposures

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A convenient and low-cost approach for obtaining high-quality gratings larger than lens apertures employs exposure beams and latent gratings as alignment tools.

Diffraction gratings are periodic structures that are used for applications involving dispersion, beam splitting, polarization, and phase matching of light. Recent developments require ever larger-size diffraction gratings for, e.g., pulse compression in chirped-pulse-amplified (CPA) laser systems, spectroscopic analysis of astronomical data, or length measurement in compact interferometers. CPA systems—a difficult but important application—are dedicated to igniting laser fusion to generate conditions similar to those found in the sun’s interior. Their great energy demands necessitate large-size, high-efficiency, low-wavefront-error, and high-damage-threshold gratings.

The main grating-fabrication method in use today, holographic exposure, requires large-aperture, low-aberration wavefronts. This restricts the size of single-exposure gratings. They currently cannot greatly exceed 1m diameter. Lawrence Livermore National Laboratory has produced 910 ×450mm$^2$ and 17521/mm multilayer dielectric gratings with low peak-to-valley values (PV) of diffraction-wavefront errors of 0.15λ, where λ is the measurement wavelength. Scanning-beam interference lithography, developed at the Massachusetts Institute of Technology, incorporates many high-accuracy control techniques into continuous, millimeter-diameter scanning exposures. This technique has also delivered 910 ×420mm$^2$ and 17401/mm gratings, with 0.2λ PV errors. Here, we report a convenient, low-cost technique—‘optical mosaic’—for enlarging the grating area using multiple exposures, i.e., we extend the capabilities of typical single-exposure systems.

For optical mosaics and other grating-fabrication techniques, the exposure fringes (i.e., the interference fringes of the exposure beams) should continuously be kept in phase and parallel relative to the substrate to write the corresponding high-quality latent-image grating (the exposed but undeveloped volume grating) in the photoresist. Latent gratings with weak
diffraction efficiency have, in the past, mainly been used for control of exposure dosage, but they are also detectable for metrology applications, according to the grating-diffraction phase-shift theorem. Hence, to control exposure beams and substrate, we adjusted the exposure fringes to high accuracy and locked them to the latent gratings. In other words, the fabrication subject (exposure fringes) and the fabricated object (latent grating) are united for alignment (adjustment and fringe locking). This makes optical mosaic essentially different from other techniques in that it eliminates drift errors from otherwise independent measurement devices (such as separate reference gratings).

We set up a mosaic system (see Figure 1) that adds attitude adjustment and phase locking based on a typical holographic exposure. After one exposure, the latent grating is written in the photore sist layer of substrate G by exposure beams I1 and I2. Next, the specially designed wedged attenuators A1 and A2 are inserted into the exposure beams to tilt and attenuate the –1st- and zeroth-order diffractions from the just-formed latent grating. The interference fringes—L fringes: see Figure 2(a)—of the diffractions are recorded by a high-sensitivity electron-multiplying CCD and employed for attitude adjustment and phase locking.

Specifically, we use the mirror M driven by piezoelectric transducer PZT_p and the spatial filter SF driven by PZT_s to rapidly and conveniently control the phase of I1 and the tilt of I2, respectively, as well as the phase and period of the L fringes. After recording a set of reference L fringes, we perform attitude

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adjustment and phase locking by aligning the L fringes to the reference fringes before and during each subsequent exposure, respectively (see Figure 2). By shifting the substrate along the grating-vector or groove directions for certain distances between exposures, an $m \times n$ mosaic is completed (where $m$ and $n$ are integers), yielding a high-quality grating area (in phase and with parallel grooves) that is much larger than the exposure aperture.

We fabricated different mosaic gratings with periods of approximately 600nm and used a Fizeau interferometer to measure their −1st-order diffraction wavefronts. Figures 3 and 4 show measurements of a 1×3 mosaic of a $60\times(42 + 27 + 27)$mm$^2$ area and a 2×2 mosaic of a $(60 + 28)\times(53 + 30)$mm$^2$ area, respectively, with all mosaic errors reduced as much as possible. The diffraction wavefronts are very flat: all fringes in the interferograms are in phase, and the measured PV errors over the full mosaic areas are much less than 0.1λ.

In summary, we have proposed and demonstrated a multiple-exposure approach to conveniently fabricate large, monolithic mosaic gratings, while maintaining low-aberration diffraction wavefronts beyond the exposure aperture. By aligning the exposure fringes (fabrication subject) to the latent grating (fabricated object), we made the entire system very compact and inexpensive, and simultaneously eliminated many possible drift errors from otherwise independent measurement devices. We will next study and apply this technique in relation to meter-sized grating fabrication, including, e.g., controlling influences of exposure aberrations and seams between adjacent exposure areas.

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References