An optimized, grid-based binary holography mask for high resolution lithography with light or matter waves

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We present a lithography technique, where a beam of neutral, metastable helium atoms is used for patterning. Such atom beams have a very short wavelength (less than 0.1 nm), even at low energies (less than 0.1 eV), thus in principle, making nanometer resolution lithography possible. Using neutral atom beams with a mask makes it possible to expose large samples at once, eliminating the sequential nature of methods like electron beam lithography. One challenge with using a neutral atom beam is that there are no ordinary transparent masks available for the patterning process, because the atoms do not penetrate solid material. However grid based binary holography (GBH), can be used to produce arbitrary patterns [1, 2].

In GBH the masks are based on a grid of open or closed holes that encode the desired pattern. This means that a mask for a matter wave beam can be made, for example by etching holes in a silicon mask. This has already been demonstrated [2]. Until now only a limited amount of theoretical work has been done on GBH, making it difficult to access its true usefullness for patterning. Here we present a detailed theoretical and numerical study of GBH [3]. We show how the same pattern can be generated with up to 80 % variation in number of open holes. We also show that masks can be made very robustly with a high tolerance to fabrication errors. Figure 1 shows simulation results from reconstructing an arbitrary pattern using GBH masks. Two different masks with different properties were used to create the same pattern. Cut-outs of these masks are shown in Fig. 2. The method is illustrated by presenting simulations and some initial proof-of-concept experimental results based on photolithography.

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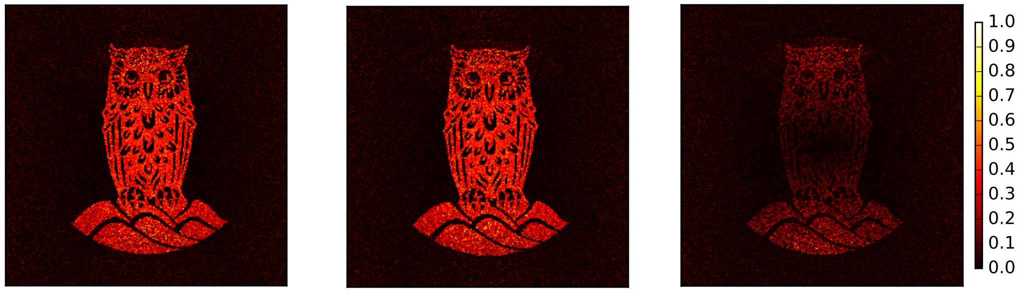
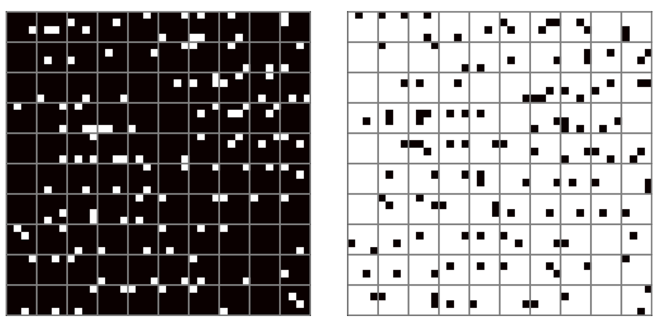


(a) $I_s^{\min}$ minimum (b) $I_s^{\max}$ maximum (c) $|I_s^{\min} - I_s^{\max}|$

FIG. 1: Simulation results that show the reconstruction of an arbitrary pattern using two different GBH masks. The masks were created for the same target pattern, but the mask used for (a) is minimally open while the mask used for (b) is maximally open. (c) shows the difference between the two figures. The main contribution to the observable difference is the difference in the noise in the reconstructed patterns mainly due to approximations in the encoding scheme. All the axes are similar and the intensity values are comparable and of arbitrary unit.



(a) Minimum (b) Maximum

FIG. 2: Parts of the masks (size 40×40 subcells) used to generate the two intensity patterns presented in Fig. 1: (a) mask with the minimum number of holes (open subcells); (b) mask with the maximum number of holes. Light (dark) colored squares represent open (closed) subcells. Gray lines show cell boundaries.