Image sensor with 20-nm resolution based on uniformly redundant arrays

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Abstract: In this paper we present an image sensor based on uniformly redundant arrays that have customizable pixel resolution below 20 nm. This sensor has applications in lithography tools that produce image intensities that cannot be resolved by conventional CCDs.

In some imaging systems such as lithography tools, features have critical dimensions (CDs) that are well below the limit of resolvability of standard image sensors such as CCDs. Although these systems have alternative means for evaluating image intensity profiles (e.g. resist line-edge profiles in a lithography system), it is often desirable to have access to the true image intensity in the image plane.

One accepted solution to this problem in certain circumstances is to scan a pinhole point by point in the image plane and capture the intensity through the pinhole on a diode, as shown in Fig. 1a. In this configuration, the pinhole size d sets the effective sensor pixel size as shown in Fig. 1b.

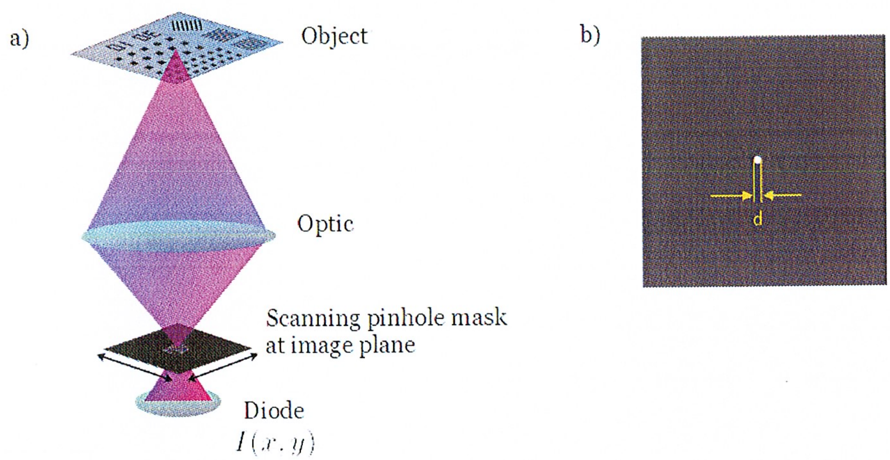

Fig. 1. a) Schematic of a pinhole image intensity monitor. b) A sample pinhole mask with resolution d.

This setup works well for when a moderate pixel size is desired; however, if extremely small pixel sizes are needed, a problem can arise where low photon flux incident on the pinhole is insufficient to overcome the diode intrinsic noise in a reasonable amount of time. The threshold at which this effect becomes relevant depends on the exact parameters at hand, but as an example, a production EUV lithography tool operating at a rate of 50 wafers per hour requiring a 20 nm pixel resolution produces an average of 10 photons per millisecond compared to 82 photons of equivalent noise in the same time period.

To increase the signal to noise ratio we implement a mask with a higher efficiency than a pinhole mask. If the true image intensity is $I_r(x,y)$ and the mask function is $M(x,y)$, then the measured intensity $I_m(x,y)$ is now given by:

$$I_m(x,y) = I_r(x,y) * M(x,y) \tag{1}$$

Solving equation 1 for $I_r(x,y)$ represents a standard deconvolution problem. In order for the solution to be well-defined, we require that the mask spectrum $\mathscr{M}(f_x, f_y)$ have no zeros. Uniformly redundant arrays (URAs) are mathematical functions that have both high efficiency (50%) and a flat spectrum, and thus are ideal structures to use as a mask in the image intensity monitor. A schematic of a URA is shown in Fig. 2 alongside a scanning electron micrograph of a 20-nm URA fabricated by the Center for X-ray Optics (CXRO).

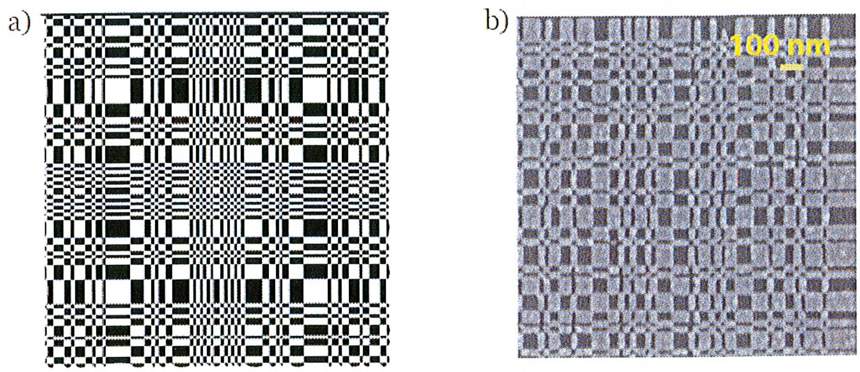

Fig. 2. a) Schematic 101 x 101 pixel URA. b) SEM image of URA made in the CXRO nano fabrication lab. Gold on silicon nitride, 20-nm half pitch.

In this case, the effective pixel resolution is set by the smallest feature dimension on the URA. However, since the URA has an efficiency that is several thousand times higher than the pinhole, it serves to enhance the signal well above the intrinsic diode noise limit.

In summary, the proposed image sensor employs a scanning URA mask with photodiode to capture the image intensity profile. The effective sensor pixel size is set by the smallest feature on the URA, which can be optimized on a case-by-case basis. The URA-based intensity monitor outperforms the conventional pinhole monitor because it has significantly increased efficiency while maintaining a flat spectrum required by the deconvolution routine.

DISCLAIMER

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