

# Microcircuit Lithography Using Holographic Imaging

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## ABSTRACT

TIR holograms have been used to generate 0.5  $\mu\text{m}$  resolution images with illumination by an Argon laser operating at 457 nm. The contact (proximity) printing geometry compatible with standard wafer processing was used for the recording and reconstruction processes. In order to eliminate the expensive and bulky construction involving a prism, a backside holographic wave coupler is proposed.

## 1. INTRODUCTION

Several different geometries were proposed to exclude the direct reconstructing beam which degrades the lithographic image and decreases its contrast. They are focused-image holography<sup>1</sup>, Fourier Transfer Holography<sup>2</sup> and computer generated masks<sup>3</sup>. A small separation distance between a hologram and a wafer allows us to more easily eliminate holographic aberration without additional aligning equipment. This leads us directly to a proximity printing configuration (in the geometrical sense) which combines the simplicity of technology for large image fields with a high resolution aberration-free image. However, the diffraction limit has restricted the resolution of a pattern which could be transferred from an original to a hologram. It is well known<sup>4</sup> that the maximum spatial frequency of a sinusoidal component still producing a diffracted plane wave in free space is  $n \leq 1/\lambda$ . In this paper, the Argon laser wavelength  $\lambda=457.9$  nm, which imposes a half-micron resolution limit, was employed.

Since Edwin B. Champagne and K.A. Stetson's pioneering work<sup>5,6</sup> there has been continuous interest in improving resolution and signal-to-noise ratios by using TIR holograms. Recently, we reported a volume holographic recording system utilizing a TIR geometry, which initially results in 0.5 micron resolution and signal-to-noise ratio better than 10dB for the reconstructed image.

## 2. EXPERIMENTAL TECHNIQUE

The feasibility of holographic lithography which employs a prism to introduce a reference beam into a TIR hologram was demonstrated in References 7 and 8.

A schematic explanation of the holographic geometry used is shown in figure 1 and 2. A transparent object (master mask), when illuminated, produces a set of plane waves according to the Fourier expansion of the transmittance.

Two sets of interference fringes are generated by each of the object plane waves. The example of a zero-order harmonic is shown in figure 2. The double fringe structure increases diffraction efficiency to as high as 80% and produces a sharp Bragg diffraction peak that can be seen from spectrophotometric measurements (figure 3). Relatively high absorption of the polymer film<sup>7</sup> that we have employed in our recording would normally produce considerable nonuniformity. But this is compensated for by the advantage of dry processing. We have not observed any significant shifting of the Bragg diffraction peak in this material during the holographic formation process. However, to avoid a heavy, bulky, construction, with an expensive prism (especially in the UV range) we propose an alternative design using backside holograms to introduce the reference and/or reconstruction beams. It results in a holographic mask consisting only of a glass substrate with holograms on both sides. The quality of the glass substrate need not be high since the holographic process has compensation ability.

The backside hologram consists of two layers containing Lippmann mirror structures and coupled transmission holograms as shown in figure 4. The Lippmann mirror serves to eliminate the non-diffracted beam behind the first transmission hologram.

The reconstructing beam is diffracted in a volume transmission hologram with fringes slanted at  $15^\circ$  to the surface. The angle of incidence of the reconstructing beam is also  $15^\circ$ . Due to the Bragg condition, the direction of the beam falling upon the outside surface must be  $45^\circ$  to produce total internal reflection. At the same time, there is no reflection from the Lippmann mirror because the  $45^\circ$  angle of incidence is far from the Bragg condition which is exactly fulfilled for a  $15^\circ$  angle of incidence of a non-diffracted beam. The result is also in agreement with Kogelnik's theory.

As a result of the process described above, we have the possibility to introduce the reconstruction/recording beam at the critical angle necessary for TIR without the use of a prism. The backside hologram was recorded on DCG and after that the other side of the glass substrate was coated with photopolymer. The pattern transferring from such a compound hologram to a wafer was done the same way as for the simple holographic mask in Reference 7. The only difference is that we do not need a prism in this case.

### 3. SPACER MAINTAINING ACCURACY

It was found both theoretically and experimentally that the most crucial point for submicron resolution holographic lithography is the separation between the object and the hologram in the recording process, and between the hologram and the photoresist plane in reconstruction. The separation distance should be kept exactly the same for both processes.

We know that the spherical aberration could be described by the term

$$\exp\left\{-\frac{i2\pi(x^2+y^2)}{\lambda_0} \frac{1}{8} \left[ 2\left[\frac{\lambda_0}{\lambda_r}\left(\frac{1}{R_i^3}-\frac{1}{R_r^3}\right)+\frac{1}{R_o^3}+\frac{1}{R^3}\right]\right]\right\} \quad (1)$$

Assuming  $\lambda_o = \lambda_r = \lambda$ , the wavelengths are equal for both steps, and reference and reconstructed beams are plane waves so  $R_r=R_o \rightarrow \infty$ . Thus, the phase shift due to spherical aberration is

$$\Delta\Phi = \frac{\pi}{4\lambda} \rho^4 \left( \frac{1}{z^3} - \frac{1}{(z+\Delta z)^3} \right) \quad (2)$$

where  $\Delta z$  is the difference from the condition of an equal separation  $z$ , and  $\rho = \sqrt{x^2+y^2}$  is the radius vector in the plane.

The system is practically free of aberrations when the intensity variations at the diffraction focus are less than 20%. This requirement yields

$$|\Delta\Phi| \leq (0.2)^{\frac{1}{2}} \quad (3)$$

The effective diameter of the portion of the hologram being transformed into a real image at any one point in the image plane is

$$\rho = z \tan \alpha \quad (4)$$

where  $\sin\alpha = \lambda v$ , from the diffraction equation. This means that the effective diameter of the portion of the hologram participating mainly in image reconstruction depends on the spatial frequency, i.e., resolution, so that

$$\rho = z \frac{\lambda v}{(1 - \lambda^2 v^2)^{1/2}} \quad (5)$$

Substituting (4) into (2) and taking (3) we finally obtain

$$\Delta z \leq z \left[ 1 - \frac{4(0.2)^2 \lambda}{\pi \tan \alpha z} \right]^{\frac{1}{3}} - z \quad (6)$$

Expanding the last inequality we have

$$\Delta z \leq 0.19 \frac{\lambda}{\tan^4 \alpha} \quad (7)$$

It can be seen from figure 5 that for high resolution ( $>2\mu\text{m}^{-1}$ ) the separation distance should be kept exactly the same for both processes. Indeed the reproducible result was consistently achieved when a fixed spacer of 50 micron thickness was used for recording and reconstruction.

#### 4. PHOTORESIST IMAGE RECORDING

In order to make present holographic techniques applicable to traditional lithography, a photoresist coated on glass was employed to demonstrate the final pattern. A Shipley 1400-27 photoresist was chosen ( $0.85\mu\text{m}$  thick) and a standard 80% diluted AZ-319A developer was used without the benefit of cleanroom conditions. The photoresist film fabrication included glass cleaning and resist spinning.

The photographs in figure 6 confirm the high resolution capability of the system. Features as small as  $0.5\mu\text{m}$  are resolved. Also, as expected, no geometrical aberrations were observed.

The master mask consisted of an e-beam of 0.5 micron width chromium lines with 1 micron separation on glass substrate. The whole length was 1 inch. The reproduced image kept the ratio of the widths of transparent and opaque parts.

There were no special precautions taken to avoid dust. Dust is visible in the photograph taken under reflected light.

#### 5. CONCLUSION

The original combination of a coupled wave hologram with TIR holography provides us the capability to generate high resolution image without employing a bulk prism. We gained high diffraction efficiency by using DCG for the backside hologram and photopolymer material for the holographic mask. By fixing the distance between holographic plate and the image plane, a reproducible aberration free result was achieved. Further theoretical calculation ensures that the technology reported is capable of making large area, submicron lithography. The submicron holographic imaging system is relatively simple and, therefore, the cost is expected to be reduced drastically.

#### 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

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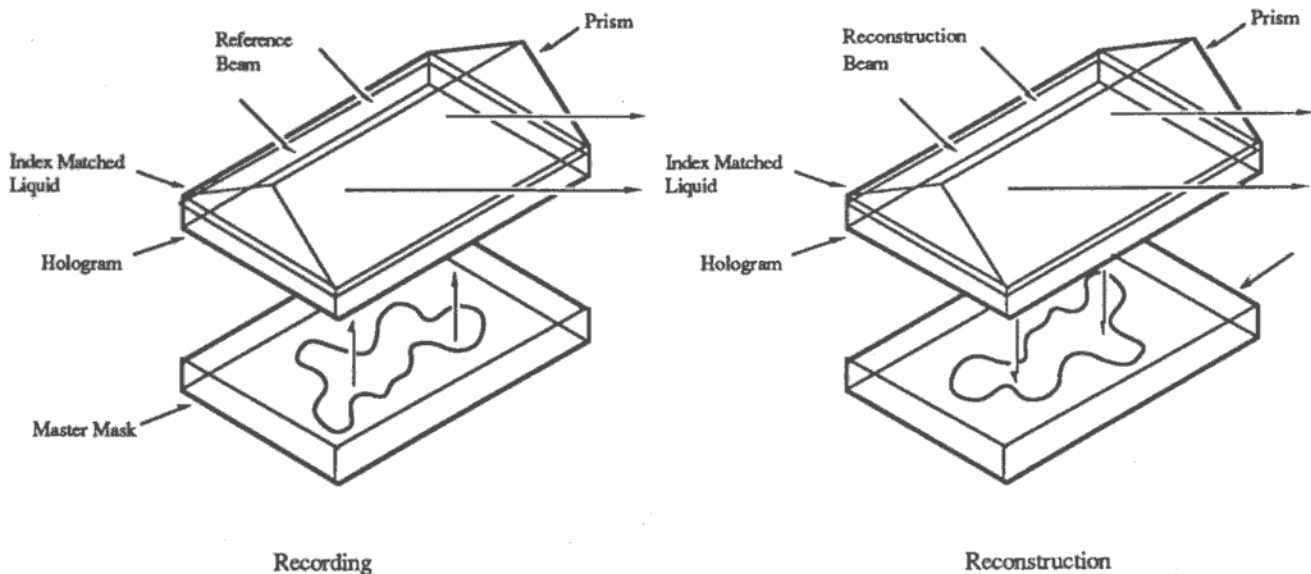


Figure 1 Holographic microlithography with TIR set up.

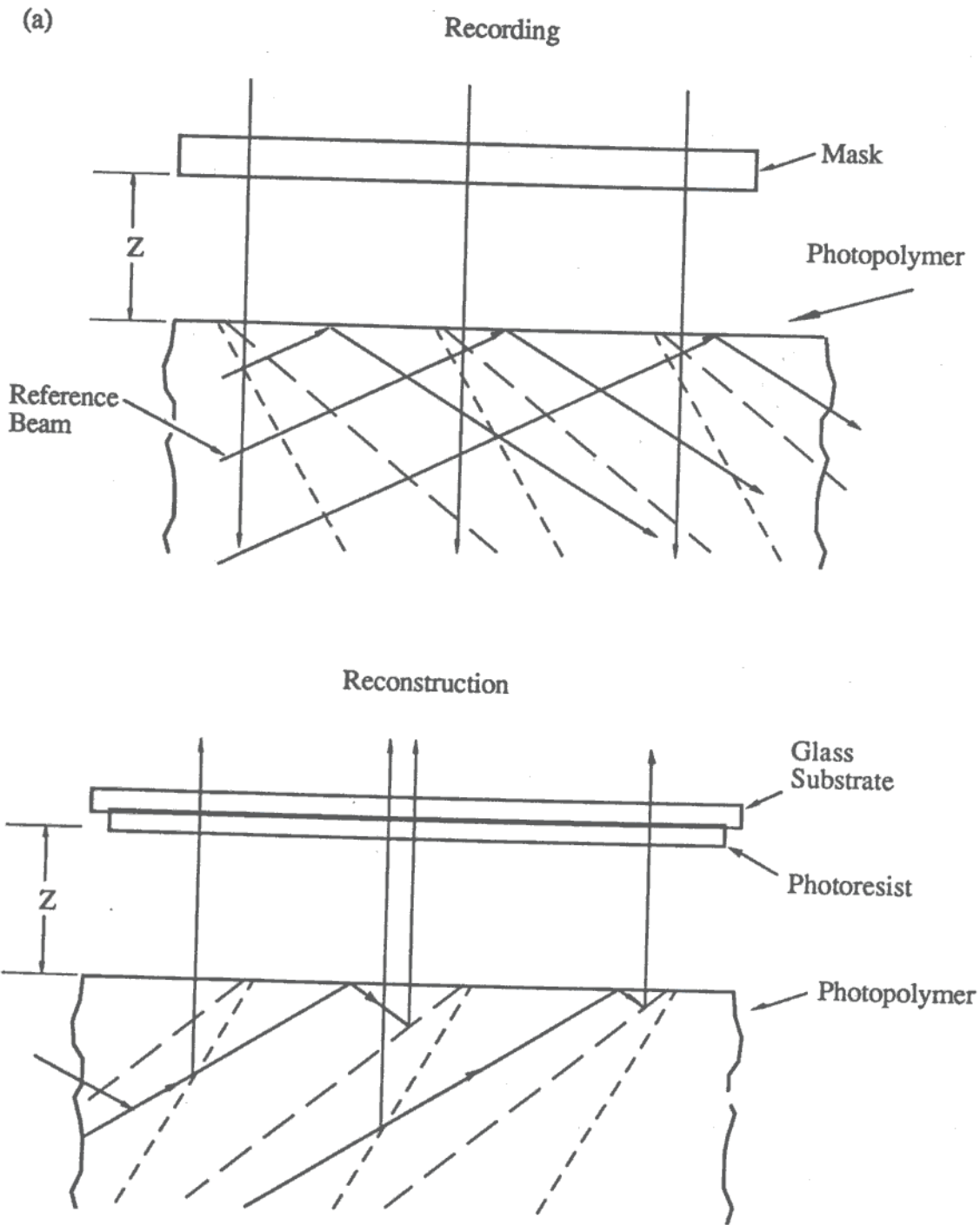


Figure 2

(a) Recording and (b) reconstruction geometries. Two sets of fringes are shown by dashed lines. The hologram has been rotated on  $180^\circ$  for readout.

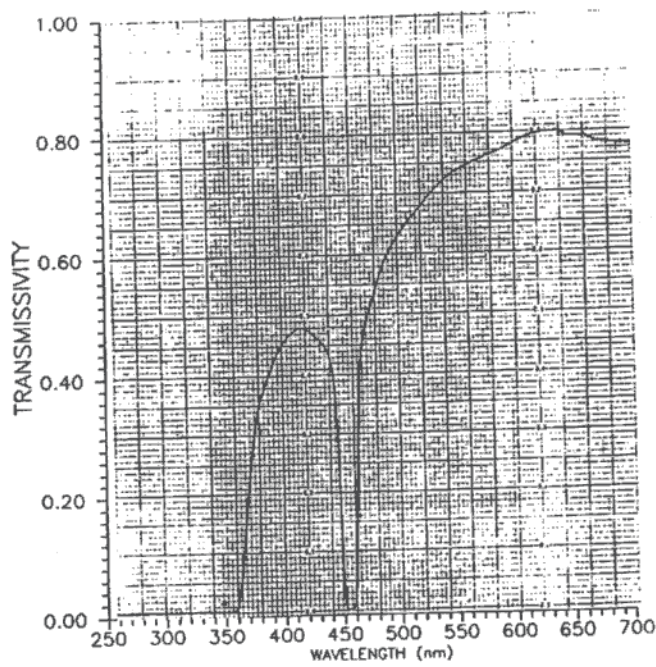


Figure 3 Spectral Transmittance of the Volume Hologram Recorded Without Mask.

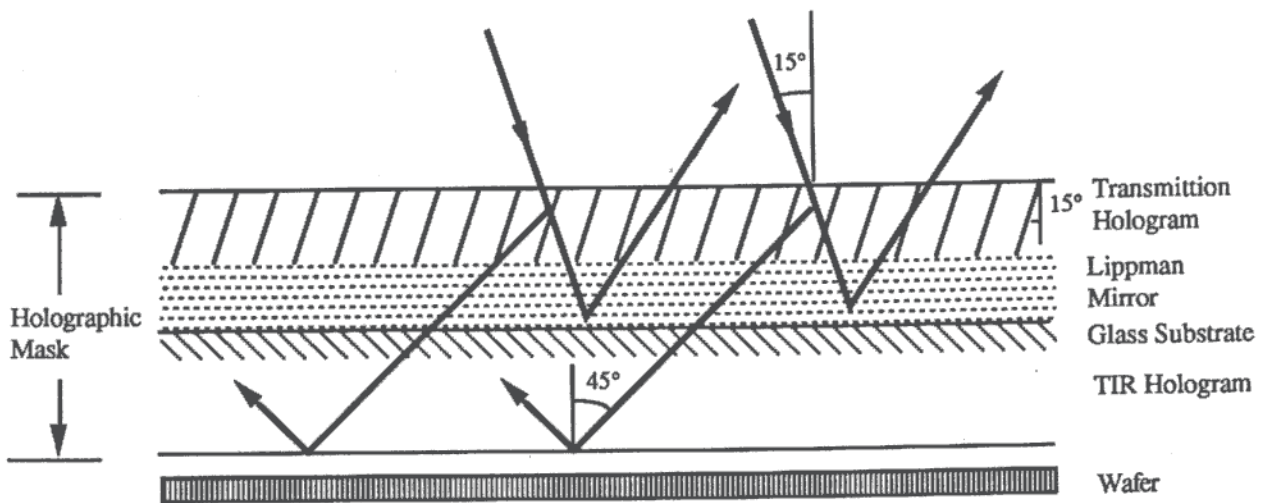


Figure 4 Backside Hologram for Reconstructing Beam Coupling. The thickness of holographic layers are exaggerated.

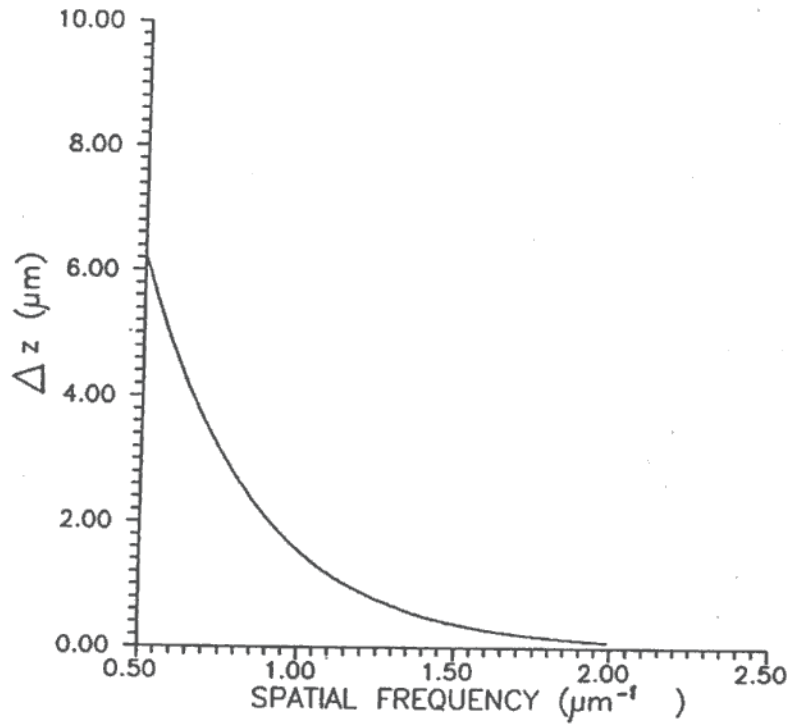


Figure 5 Accuracy of Equal Separations for the Recording and the Reconstruction Process.

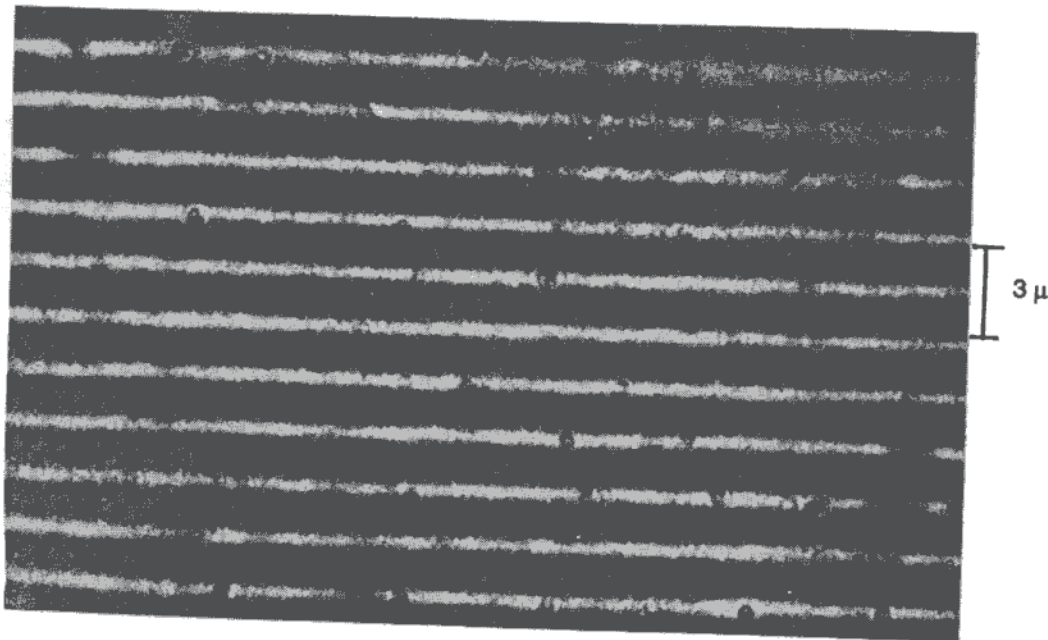


Figure 6 Photograph of the 0.5 micron resolution holographic image recorded on photoresist. Magnification 1500x.