Extended Abstracts of the 16th (1984 International) Conference on Solid State Devices and Materials, Kobe, 1984, pp. 7-10

Invited

Submicron Lithography Using Contrast Enhancement

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Contrast Enhancement, a method for the production of submicron photopatterns is reviewed. With this technique, good quality images are obtainable even under very low contrast illumination through the use of photobleachable materials in conjunction with standard photoresists. The method consists of applying a thin photobleachable layer to the photoresist surface prior to the conventional exposure step. The bleachable layer (contrast-enhancing layer or CEL) is subsequently removed and the resist developed in the ordinary way. Submicron patterns fabricated using an Optimetrix 10:1 DSW system demonstrate that the CEL is capable of very high resolution.

CONTRAST ENHANCEMENT CONCEPT

Today a large fraction of optical lithography is done by projection techniques in which the aerial image of a mask is used to expose the photoresist. As line size decreases, contrast is reduced and discrimination of darker areas from the lighter areas of the pattern becomes increasingly difficult. The contrast enhancement technique described within improves the ability of a photoresist to effect this discrimination. Contrast enhancement is based on the use of photobleachable materials which are initially relatively opaque, but following some dose of radiation, become relatively transparent. The transmission properties of an idealized bleachable layer are shown in Figure 1. When the aerial image of a mask is incident on such a layer, the regions of the bleachable layer that are exposed to the highest intensities bleach through first, while those parts of the layer that receive the lowest intensities bleach through at a later time. The dynamics of this bleaching process are depicted in Figure 2 using a computer model.(1) If the exposure is stopped at a time corresponding to Figure 2e, the transmission of the bleachable layer most nearly corresponds to that of the original mask. When such a material is coated on top of a conventional photoresist layer, the resulting composite can be used at lower contrast than the resist layer alone. This will be true if the photoresist is sensitive enough to be exposed in a time short compared to the bleaching time. The bleachable layer essentially forms an in situ contact mask for the photoresist layer. The net effect of this in situ mask is to increase the contrast which is incident on the photoresist over that of the aerial image. This is the origin of the terms contrast enhancement (CE) and contrast enhancing layer (CEL). CEL adds only two steps to the conventional process, as shown in Figure 3, compared to 6-10 steps required for multilayer processes. Thus CEL yields many of the advantages inherent to multilayer processes, while retaining much of the simplicity and cost effectiveness of conventional processing. It has the further advantage of retaining conventionally used positive resists, with their well-understood dry etch and adhesion properties.

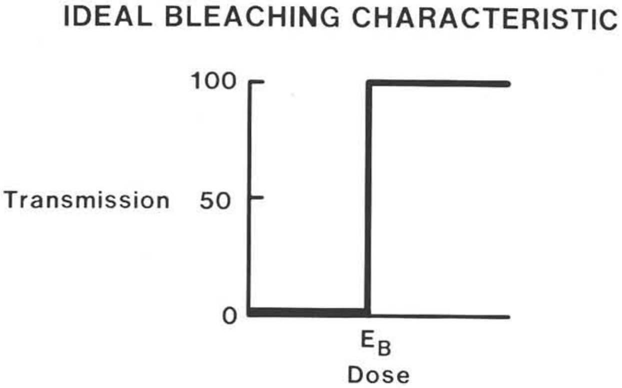

Figure 1. Transmission of ideal bleachable layer.

SPECTRAL CONSTRAINTS

The intended application of CE techniques to submicron optical lithography gives rise to several physical and chemical constraints on the contrast-enhancing layer itself. The CE layer must be simultaneously thin and optically dense. The thickness requirement is made by the narrow depth of focus of high resolution optical systems. This limits the thickness to a range of less than 1 μ. Because the CEL must be optically dense, it is necessary that the photochemical constituents of the layer be strongly absorbing. The wavelength range over which these materials operate is constrained to match the optical projection system of interest. Most DSW systems operate at either 436 nm (G line), 405 nm (H line) or more recently 365 nm (I line). Due to the strong initial absorption required by CEL, it is difficult to find a single photochemical system that covers the entire 365-436 nm range. This is because the strong but somewhat narrow absorption bands of organic dyes used for CEL limit the wavelength range over which any one dye is useful. Figure 4 shows the absorption spectrum of Altilith CEM-388,(2) a material which will operate at the H and I lines, but not at G line. Previously published results(3,4,5) were obtained using this material. Recently a new material which is useful at the G and H lines has been developed. The absorption spectrum of this material, CEM-420, is shown in Figure 5. The photobleaching properties of this new material are quite similar to CEM-388. The lithographic performance of the new material is also essentially the same as CEM-388 at H line, where the absorption spectra overlap. At G line, however, the new material performs where the old will not.

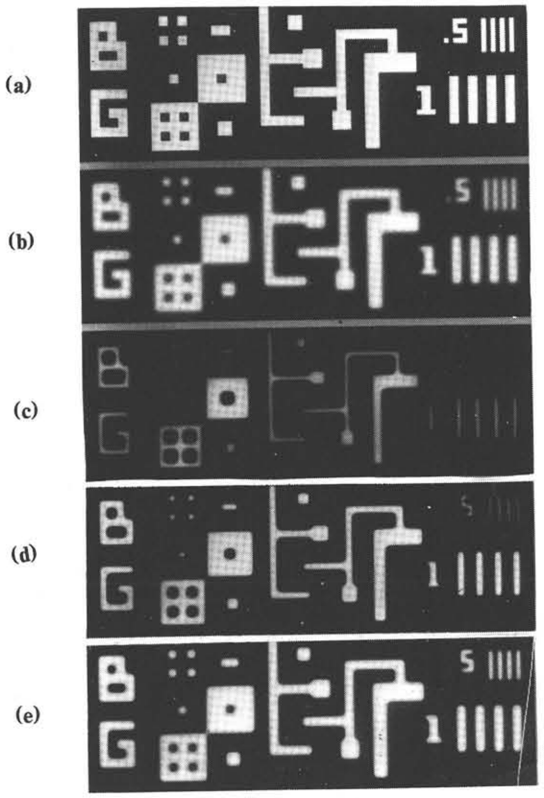

Figure 2. **Computer model of photobleaching process: (a) mask pattern, (b) aerial image, (c-e) transmitted image at successive times.**

RESULTS

The CEL process is compatible with a variety of exposure tools, but all of the results presented here were obtained on an Optimetrix 10:1 DSW operated at either 405 nm or 436 nm with a numerical aperture of 0.32. The performance of CEM-388 is demonstrated in Figure 6 where 0.7 μ and 1.5 μ grating patterns were imaged under identical conditions with and without CEL. The edge acuity of the CEL process is clearly superior to that of the conventional positive resist. Improved edge acuity results in improved resolution and linewidth control. Further, the vertically walled resist profiles often improve linewidth control obtainable in subsequent dry etching processes. Line-space patterns of similar quality have been obtained using the experimental G-H line material. Figure 7 depicts a 0.65 μ line-space pattern fabricated using CEM-420 at G line. This material is of interest because the majority of DSW systems are currently in use to operate at G line.

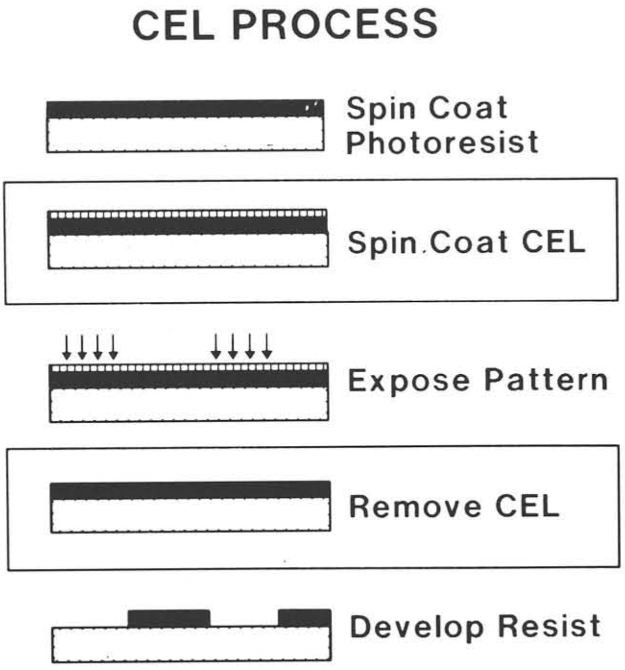

Figure 3. **Photoresist process incorporating CEL concept. Added CEL steps are outlined in boxes.**

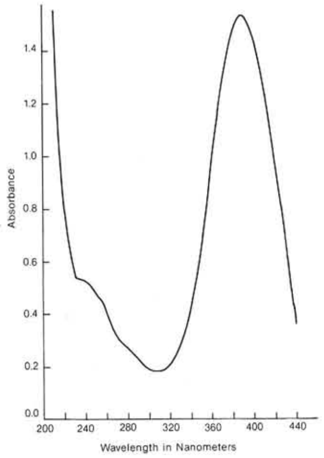

Figure 4. **Absorption spectrum of Altilith CEM-388.**

Figure 8 depicts a gate level photoresist pattern produced using CEL. The resist thickness is approximately 0.25 μ and the gate width is 0.4 μ. The surface below the resist is polysilicon. Working devices were fabricated using this process, although CEL was used only on the gate level. The remaining masking steps in the process were not critical. A photograph of one of the resulting devices and its electrical characteristics is shown in Figure 9. The smallest line-space pattern obtained to date using the CEM-388 material is shown in Figure 10. The contrast at which this was imaged has been measured and is below 10%.

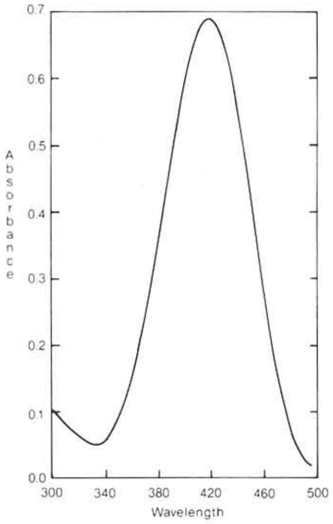

Figure 5. Absorption spectrum of experimental material CEM-420.

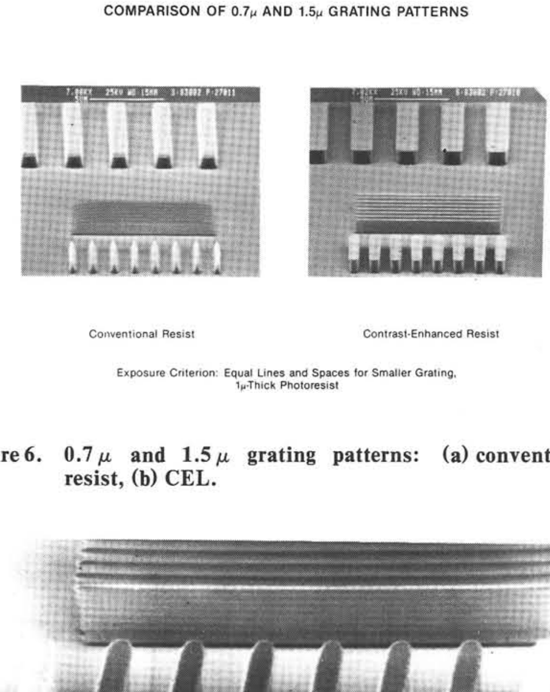

Figure 6. 0.7 μ and 1.5 μ grating patterns: (a) conventional resist, (b) CEL.

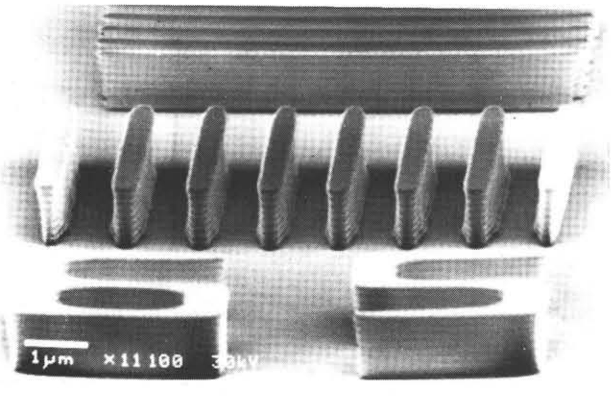

Figure 7. 0.65 μ pattern exposed at G line using CEM-420.

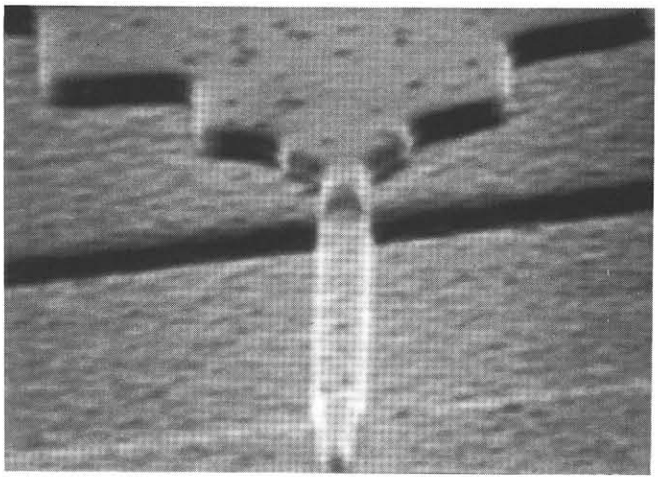

Figure 8. Gate level photoresist pattern fabricated using CEL. Gate length is 0.4 μ.

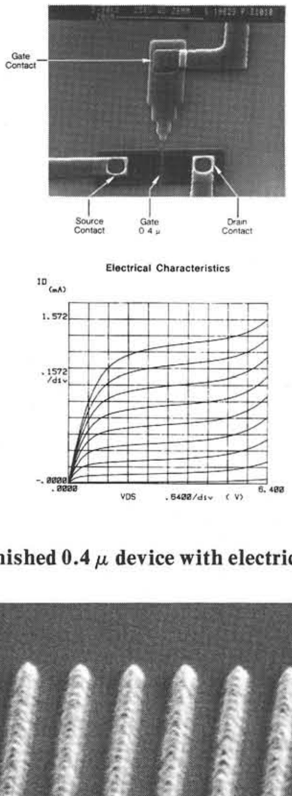

Figure 9. Finished 0.4 μ device with electrical characteristics.

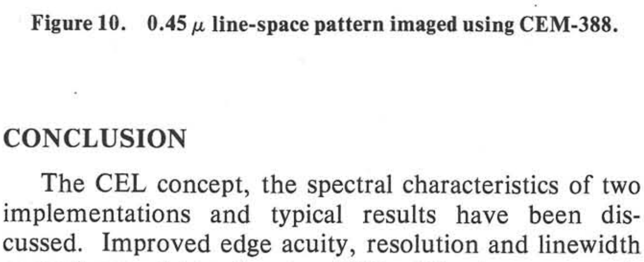

Figure 10. 0.45 μ line-space pattern imaged using CEM-388.

CONCLUSION

The CEL concept, the spectral characteristics of two implementations and typical results have been discussed. Improved edge acuity, resolution and linewidth control are obtained using CEL. The improvements obtainable with CEL, taken with improved optical systems, should provide a viable, low cost approach to submicron lithography.

REFERENCES

1. B.F. Griffing and W.E. Lorensen, "Two Dimensional Modeling of Contrast Enhanced Lithography," *Proceedings of SPIE 469,* pp. 102-107.
2. Previously named CEM-2, this material is now commercially available from GE Silicone Products Division, Waterford, New York.
3. B.F. Griffing and P.R. West, "Contrast Enhanced Photoresists - Processing and Modeling," *Proceedings of the Sixth International Conference on Photopolymers,* Ellenville, New York, November 1982.
4. B.F. Griffing and P.R. West, "Contrast Enhanced Photolithography," *Electron Device Letters EDL-4,* p. 14-16 (1983).
5. B.F. Griffing, P.R. West, and B.A. Heath, "0.4 Micron Gate Length Devices Fabricated by Contrast Enhanced Lithography," *Electron Device Letters EDL-4,* p. 317-30 (1983).