Deep UV Photolithographic Systems and Processes

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Deep UV [200 to 300 nanometers (nm)] photolithography has received much recent attention because it promises higher resolution than conventional exposure technology. Except for the change in wavelength from the 400 nm region, the exposure technology would remain virtually unchanged. We will discuss resist materials and processes explored in the last few years for optimization of deep UV lithography. Particular emphasis is placed upon the chemistry of resist design, multilevel processing schemes, and new sources for deep UV exposure.

INTRODUCTION

Optical lithography is the dominant technology for fabricating silicon integrated circuits. However, as feature sizes approach 1 micrometer (μm) diffraction effects proportional to the exposure wavelength limit the resolution that is needed to define higher density circuitry. Other technologies such as X-ray, e-beam, and ion beam lithography, which do not suffer from diffraction are being developed. However, each of these technologies in turn suffers from other problems. One method of extending the usefulness of optical lithography is to shift the exposure wavelengths into the deep UV (200 to 300 nm) region. The advantages of using shorter wavelengths are well known. Greater resolution can be obtained for a given numerical aperture (NA) system or, for a given resolution, greater depth of field can be obtained with a smaller NA. Except for the change in wavelength from the 400 nm region to the 200 to 300 nm range, the technology would be essentially the same as that of conventional photolithography. These considerations have led to extensive research activities in the development of new resists, new sources, and new imaging schemes for deep UV lithography.

We will discuss some of the resist materials and processes developed in the last few years for the exploration of deep UV lithography. Particular emphasis will be placed upon the chemistry of resist design.

RESIST DESIGN

Positive Resist Chemistry

Positive resists generally involve either of two different mechanisms. One involves photochemical chain scission in which exposure causes a reduction in polymer molecular weight, thereby increasing solubility in a suitable developer solvent. The other mechanism involves a polymer matrix-solution inhibitor system in which a solubility inhibitor, dispersed in an acidic polymer, is photochemically destroyed, rendering the exposed areas more soluble in aqueous alkali.

The poly(methyl methacrylate) (PMMA) or poly (methyl isopropenyl ketone) (PMIPK) chain scission resists are capable of excellent resolution, but are rather

insensitive because of low absorption at $\lambda > 230$ nm, the region of significant mercury lamp output.

We decided to base our new chain scission resists on PMMA because of its non-swelling properties in a number of convenient developer solvents. The first approach we followed was the incorporation of small (6 to 20 percent) amounts of 3-oximino-2-butanone methacrylate, a group that was expected to confer enhanced photosensitivity to the methacrylate polymer, into PMMA (*Fig. 1*)(1, 2). These copolymers have a strong absorption at ~220 nm whose tail, which extends to 250 nm, substantially improves the absorption characteristics and the photosensitivity of PMMA. The N-O bond in these esters is photochemically labile yet sufficiently thermally stable to be compatible with the various processing steps. We have extensively evaluated such copolymers as resists and have found them to be capable of 1 μm resolution and to be quite sensitive. The sensitivity of the copolymers can further be improved by adding p-t-butyl benzoic acid as a photosensitizer or by
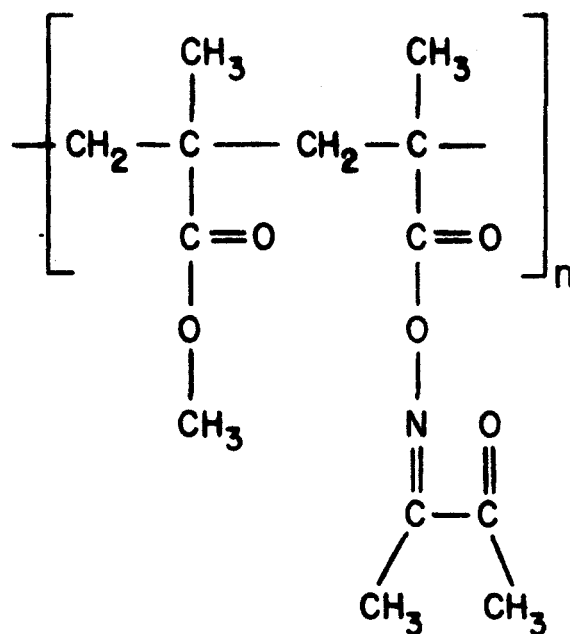

Fig. 1. Schematic showing copolymer of PMMA and small amounts of 3-oximino-2-butanone methacrylate.

terpolymerizing them with methacrylonitrile (3,4).

Hartless and Chandross (5) have incorporated small amounts of indenone into the methacrylate backbone (Fig. 2), again in order to increase the sensitivity of PMMA. The copolymer, poly(methyl methacrylate-co-indenone) (PMI), has strong absorption bands in the 230 to 300 nm region and has a momochromatic sensitivity at 248 nm of 0.02 to 0.06 joule per square centimeter (J/cm²). Resolution of 0.75 μm lines and spaces has been achieved with a projection printer modified for short wavelength exposure. The photodegradation mechanism suggested for this copolymer is based on the well known Norrish Type I α-cleavage of ketones.

A thermally crosslinkable positive resist for deep UV photolithography has been reported by Yamashita, et al. (6) (Fig. 3). The resist, a copolymer of glycidyl methacrylate and methyl methacrylate degrades upon.irradiation with a D₂ lamp and has a sensitivity of 0.25 Joule per square centimeter (J/cm²). The resist's sensitivity is rather surprising because its absorption spectrum is essentially identical to that of PMMA. It can be cross-linked by heating at temperatures above 170°C after delineation, thereby improving the adhesion and thermal stability of the resist image.

The classical positive photoresists based upon a solution-inhibition mechanism are unsuited for the deep UV. These materials consist of a novolac resin and a photoreactive solution inhibitor whose combined absorbance renders these materials too opaque for exposure, except for a narrow shallow exposure window at ~260 nm. Attempts to expose the entire thickness of the resist film result in overexposure of the upper levels of the resist, giving overcut profiles upon development.

There have been two reported attempts to design materials which circumvent these absorption problems. Willson, et. al. (7) have evaluated a resist formulated for the deep UV that is based upon the use of 5-diazo-Meldrum's Acid and related derivatives (Fig. 4) as sensi-
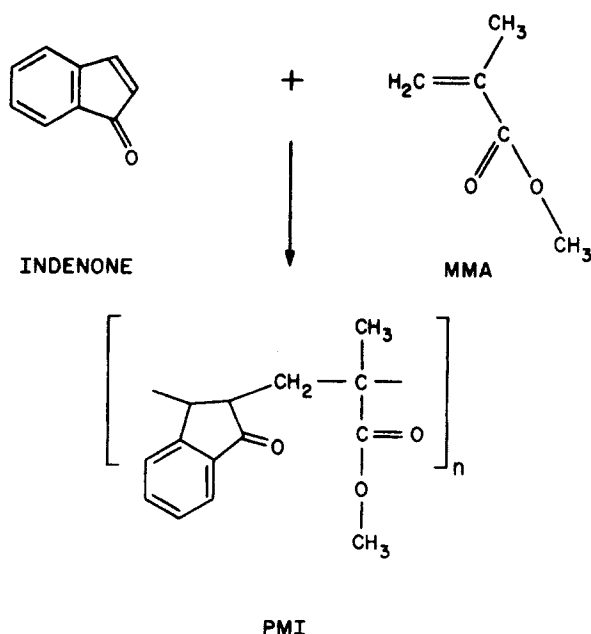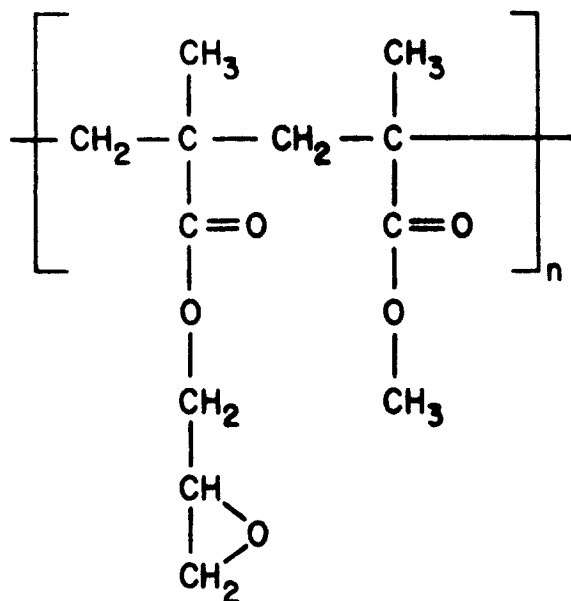
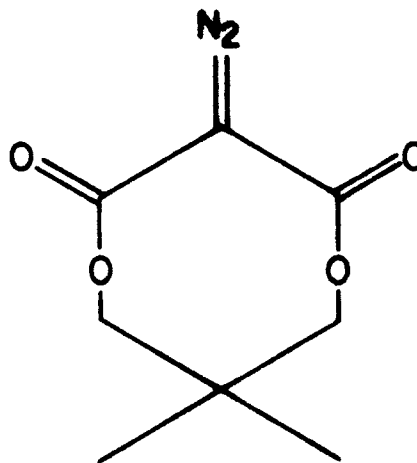Fig. 3. A thermally crosslinkable positive resist of glycidyl methacrylate and methyl methacrylate.

Fig. 4. 5-Diazo Meldrum's Acid for use as a solubility inhibitor in cresol-formaldehyde resins.

tizers for cresol-formaldehyde novolac resins. These compounds do not absorb at long wavelengths, are insensitive to ambient light, and the photoproducts are transparent. However, resist films tend to lose sensitizer during pre-baking. The resists showed reasonable sensitivity and appeared capable of high resolution, but profiles were poor because of severe attenuation of light by the novolac resin.

We have reported experiments with a deep UV (230 to 300 nm) positive resist based upon a solution inhibition mechanism (Fig. 5) (8, 9). The resin is an optically transparent copolymer of methyl methacrylate and methacrylic acid that is soluble in alkaline developers but is protected from dissolution by a photosensitive solution inhibitor. The latter is one of a family of o-nitrobenzyl esters of large-molecule organic acids such as cholic acid. It is initially insoluble in aqueous alkaline developers but is cleaved to yield base soluble components upon irradiation. This resist system has good sensitivity for λ < 300 nm and it can be made sensitive to longer wavelengths by use of external photosensitizers.
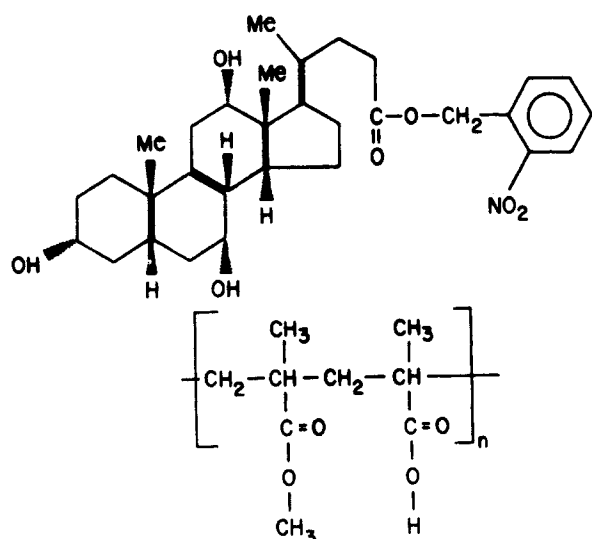
INDENONE   MMA

PMI

Fig. 2. Schematic showing copolymer of methyl methacrylate and indenone.

Fig. 5. *o-Nitrobenzyl cholate/methyl methacrylate methacrylic acid deep UV resist.*

It is capable of 0.5 μm resolution and has unusually high contrast ($\gamma > 5$). Appropriate substitution can be used to enhance the absorption characteristics of the ester and thereby improve the photochemical response of the system (10).

Negative Resists

There has not been a great deal of research interest in negative resists for deep UV lithography because their resolution is generally limited by swelling during the development step. However, a negative deep UV resist, MRS, has been successfully applied to 1:1 projection printing by Matsuzawa, *et. al.* (11, 12). The resist (*Fig.* 6), a mixture of phenolic resin and an aromatic bis-azide
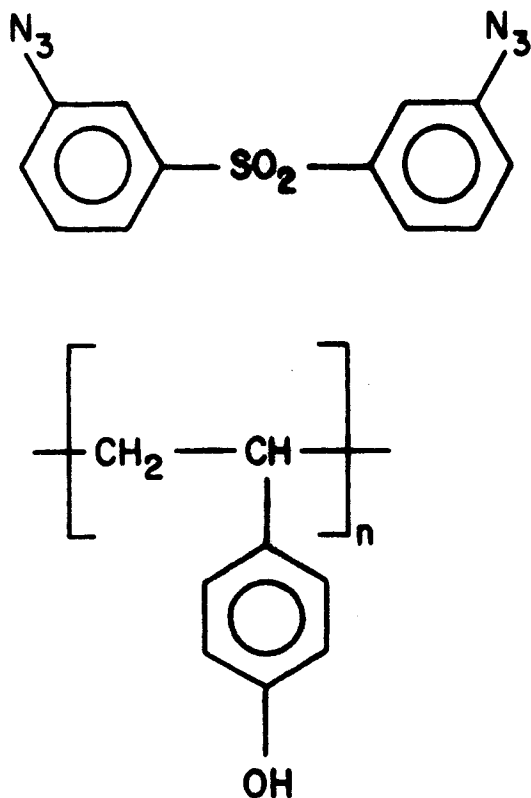

Fig. 6. *Negative resist, MRS, developed for deep UV lithography.*

is very strongly absorbing and, therefore, is not affected by reflections from wafer surfaces. Additionally, the insoluble surface layer of the exposed area acts as an etching mask while the alkaline developer removes soluble portions of the resist, enabling the system to resolve fine features. Careful consideration must be given to developing conditions.

MULTILEVEL PROCESSING SCHEMES

Modern optical systems for projection lithography are capable of resolving submicron features under ideal conditions. However, as feature sizes approach 1 μm, process control problems such as resist thickness variations (from steps on the wafer), surface reflectivity, and resist striations severely limit useful resolution. Many of these problems can be eliminated through the use of multilevel resist systems.

Lin (13) has reported a photoresist process (*Fig.* 7) which consists of a thick deep UV light sensitive resist (PMMA) as the bottom layer and a thin conventional positive resist (HPR-204) as the top layer. The technique is capable of generating <2μm features on substrates with normal device topograph. PMMA is applied to a substrate to give a nominal film thickness of 1.5 μm. A thin (.3 to .9 μm) layer of HPR-204 is then coated onto the hard baked PMMA surface. The top layer is patterned by exposure with a projection printer and developed. The PMMA is then flood exposed with deep UV light, using the HPR-204 as a contact mask, and developed. Several variations of this scheme have been re-
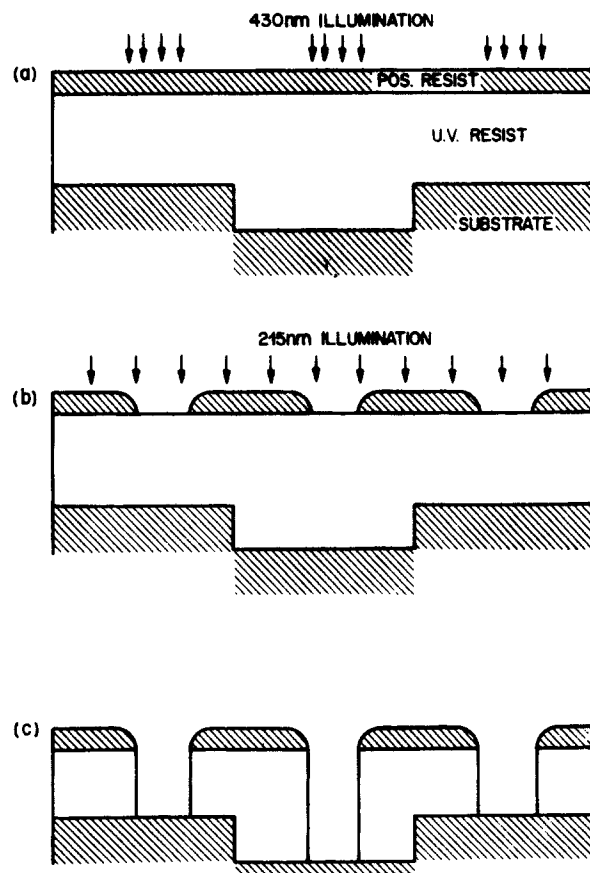

Fig. 7. *Schematic showing bi-level process for photolithography.*

ported including the use of an intermediate silicon dioxide or silicon nitride layer, (14) the use of polysiloxanes as the top layer, (15) and the use of Ge-Se doped with Ag_2Se as the top layer (16).

LASER SOURCES

The use of high-power excimer lasers for lithography has been described by Kawamura, *et. al.*, (17) and by Jain, *et. al.* (18). These lasers eliminate a chronic problem that has limited the widespread application of deep UV lithography-long exposure times caused by low emission in the deep UV from conventional arc lamps. The power outputs from excimer lasers enable exposure of 5 inch wafers in a matter of seconds.

CONCLUSIONS

Deep UV exposure is a promising technique for extending conventional lithography to the 1 μm feature size range. We have discussed the efforts of various groups to develop resists and processing schemes for this technology.

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