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Evaluation of Chemically Amplified Deep UV Resist for Micromachining using E-Beam Lithography and Dry Etching

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The electron-beam response of new chemically amplified positive multi-component ARCH-resist family (ARCH and ARCH2) and the suitability of pattern transfer through single layer has been evaluated. The electron-beam lithographic parameters for thicker layers (1-2μm) of these resists and the optimization possibilities of the exposure and etching conditions were investigated as well. Under fixed resist-handling processes, both resists exhibit high sensitivity (< 10μC/cm²) and an enormous high contrast. The study includes the effects of resist-process variations on the global 3-D resist-relief structure. Vertical side-walls of the resist profile is a necessary condition for a successful deep-, and a good CD-controlled anizotropical pattern transfer with high aspect ratio of structures into the substrate.

1. INTRODUCTION

Conformal deep structure transfer with high anisotropy into the substrate are becoming increasingly important for microfabrication. Various Chemically Amplified Resists (CARs) types have recently emerged with high resolution, sensitivity, and adequate plasma process compatibility. To date, the approach of resist chemical amplification seems to be most promising for DUV, x-ray, and e-beam applications, but the above mentioned advantages are paid for by increased pre- and post-exposure processing complexity which reduces the process latitude and the resulting CD-control. The most obvious discrepancies observed between the designed and obtained resist geometries for commercially available CARs are caused by instabilities in the delay times between the prebake-exposure-postbake process periods. For positive CARs, formation of an airborne contaminated low solubility surface layer causes the so-called "T-top" profiles [1], or "filling" and "bridging" effects. It has been shown that these effects strongly deteriorate the pattern profile [2]. A well-working micromechanical structure needs pattern transfer with vertical side-walls and minimum CD-losses. The most critical factor in this is the 3-D shape of the relief structure [3]. This applies for relatively thick resist layers as well.

In this work new multicomponent CAR materials, called ARCH and ARCH2 (Advanced Resist CHemically-amplified, developed by O.C.G. Microelectronics Materials, Inc.), were investigated in connection with direct-write shaped Electron-Beam Lithography (EBL) and Reactive Ion Etching (RIE). The aim of this paper is to enlarge the scope of the existing basic works about the chemistry of ARCH [4,5] and ARCH2 [6] to report our results in areas of EBL and dry-etching applications in micromachining, and a comparison of lithographic parameters of both resists with other conventional CARs.

2. EXPERIMENTAL

The process sequences for both resists are shown in Table 1. Because we are interested in the dry etching of deep micromechanical structures, thicker resist films are required. Typically, 0.7 to 2μm thick coatings of ARCHs were applied without protective over-coating. Exposures were performed on an e-beam pattern generator operating at 30keV with 50nm minimal shot size. All resist samples were removed immediately after exposure from the lithographic system and were subsequently post-exposure baked on a Hot-Plate (HP). Various Pre-

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Bake (PB) and Post-Exposure Bake (PEB) temperatures and duration were studied using a very fine exposure wedge. The resists were developed in 0.26N and 0.13N TMAH by 30s and 60s immersion.

Table 1.

Process	ARCH / ARCH2
Wafer priming	HMDS - 60s
Resist spin coating	0.7µm - 6000 rpm 1.0µm - 2350 rpm 1.5µm - 1000 rpm 2.0µm - 500 rpm
PB on HP in air	110°C / 130°C for 60 s
E-Beam Exposure	30keV shaped-beam
PEB on HP in air	110°C for 60 s
Development (immersion)	OPD 262 / OPD 4262 30 and 60 s
Rinse	DI-water / 20 s
Dry spinning in air	1000 rpm / 60 s
Hard-Bake (HB) on HP	120°C / 60s

3. RESULTS AND DISCUSSION

3.1. ARCH and ARCH2 resist response

A comparison of the dissolution curves of ARCHs with PMMA and with other CARs as AZ PF514 (HOECHST), CAMP6 (OCG) are shown in Fig. 1. ARCH exhibits the best form of characteristic curve with high contrast and small R_0 (=dissolution rate of unexposed resist) for PB and PEB at 110°C. For PB and PEB>125°C we observed 35% resist film thickness loss after development in 0.26N TMAH. At temperatures >150°C the originally positive-tone ARCH works as a negative resist (Fig. 2). The image reversing of ARCHs starts (for normal processing conditions and overexposure) at much higher doses than for AZ PF514-resist (see Fig. 1). Dark (unexposed) film erosion was studied and is presented in Fig. 3 where remaining thickness is plotted vs. development time for ARCHs in TMAH developers of various concentrations. As shown in Fig. 5 the changes in ARCHs sensitivities are strong up to 60s of both PEB and development times but remain nearly constant after 120s. This correlates with our observations where the changes in resist profiles for development times for 30 and 60s are negligible (Figs. 4 (b,c)). The characteristics of resist-relief structures obtained for a variety of

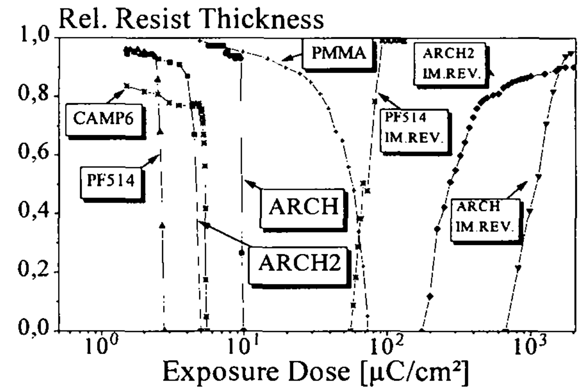

Fig. 1. Comparison of characteristic curves of ARCHs with other positive CARs.

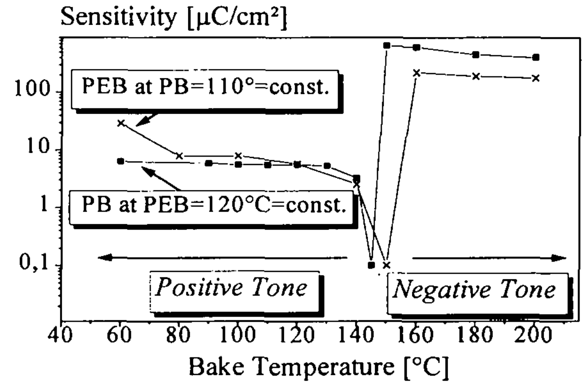

Fig. 2. The changes of ARCH-resist properties varying the PEB and PB temperatures.

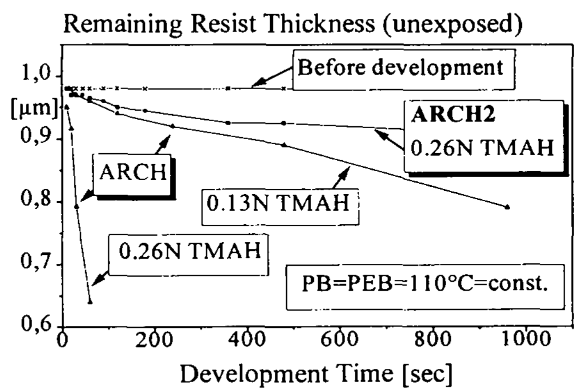

Fig. 3. Losses in the original unexposed resist film thickness varying the development time and developer concentration (dark erosion + PEB-loss).

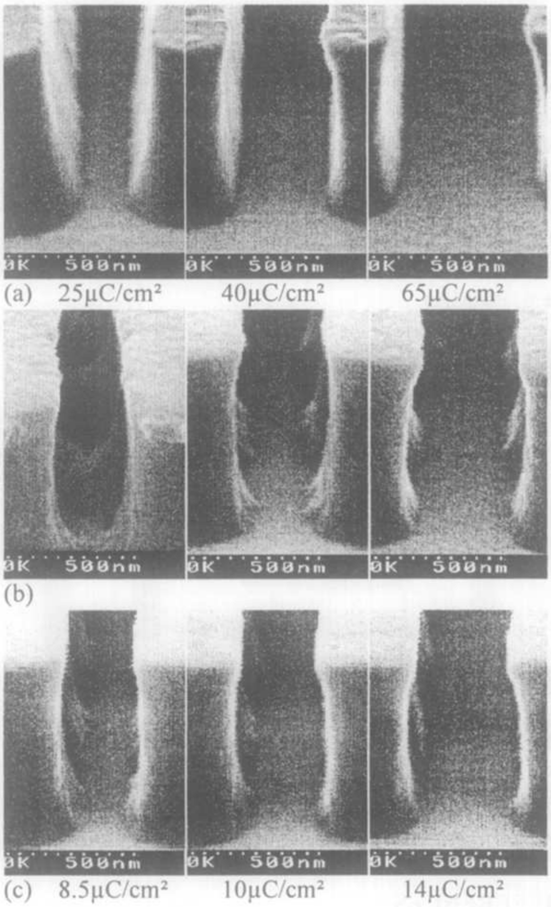

Fig. 4. Changes in resist-image profiles for :
(a) ARCH for 30s development in 0.13N TMAH;
(b) ARCH2 for 30s and (c) 60s in 0.26N TMAH.

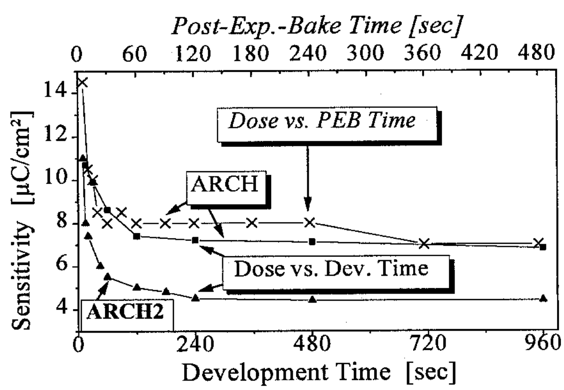

Fig. 5. Dependence of ARCHs sensitivities on PEB-duration and development time.

processing conditions and exposure parameters for isolated lines and proximity-affected structures (see Figs. 4 and 6) helped to find a way to optimize the process, by using the calculated electron energy deposition in the irradiated resist volume. Details of this study will be published elsewhere upon completion.

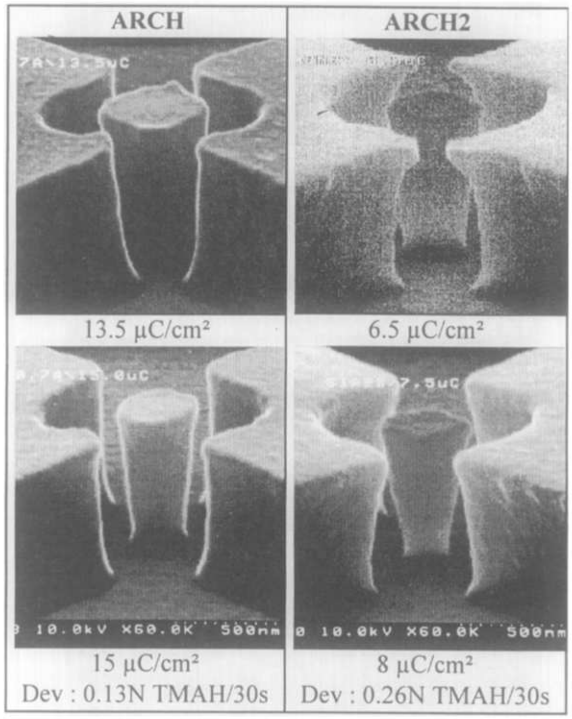

Fig. 6. Resist profiles of doughnut-like exposed structures in ARCH and ARCH2.

3.2. Reactive ion etching

The masking capability of ARCH and ARCH2 resists in fluorine and chlorine containing plasmas was examined. For SiO_2 etching in CHF_3/Ar plasma the etch selectivity SiO_2 to ARCH (ARCH2) was ~15. Fig. 7 is an illustration of RIE processes used to etch through 3μm SiO_2 by using ARCHs as masking layers. High etch selectivity of silicon to resist and very smooth silicon bottom was achieved. In periods of 200s the BCl_3 gas flow was switched on/off. In this way the formation of oxidised unsaturated halogenated film (micro-masking) onto the bottom surfaces may be prevented. With such gas „chopping“, etch rates of 200 and 30nm/min for Si and ARCHs respectively were achieved; whereas in the case of permanently adding BCl_3 to Cl_2 the etch rate for Si was 180 nm/min and for ARCH and ARCH2 55, 62nm/min respectively. In Fig. 8, an SEM of a stencil mask is shown which was fabricated by using the process described above to etch through 6μm of Si masked by ARCH resist [6].

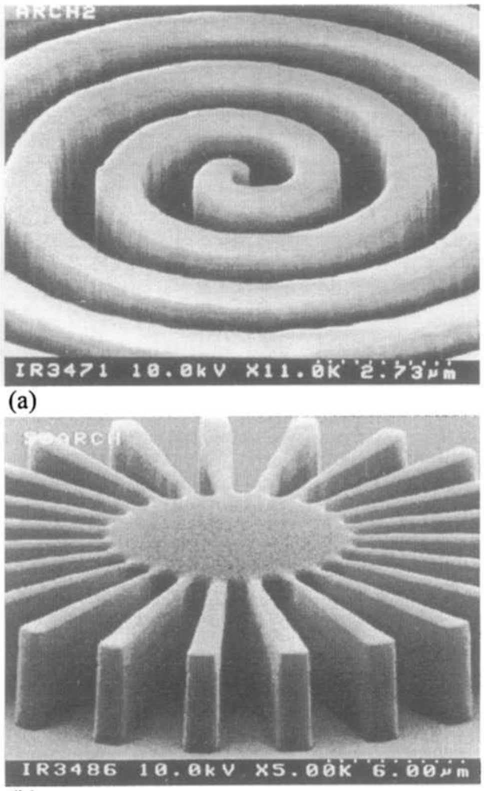

Fig. 7. Patterns etched into 3μm thick SiO_2 through (a) 1μm thick ARCH2 and (b) 2μm ARCH resists.

4. CONCLUSION

We have presented results of EBL and RIE performances of positive 3-component ARCH and 2-component ARCH2 resists. The possibility for fabrication of deep etched SiO_2 mask structures for silicon deep-trench etching through single layer of ARCHs (for fabrication of open-stencil masks on Si-membranes, grating structures for x-ray diffraction and micromechanical parts) has been demonstrated. It was shown, that under appropriate process conditions a high degree of pattern fidelity (vertical profiles and micrometer non-orthogonal curved details) down to 0.5μm is possible to transfer in 1μm to 2μm thick ARCHs resists with e-beam pattern generator at 30keV. The drawing of such structures require a precise pattern-to-pattern exposure control according to the process simulation. Therefore, it was important to determine the main lithographic parameters of ARCHs and the distortion-effects correction possibilities (proximity) down to sub-0.5μm dimensions, where a more powerful correction is required than for conventional resists (e.g. PMMA).

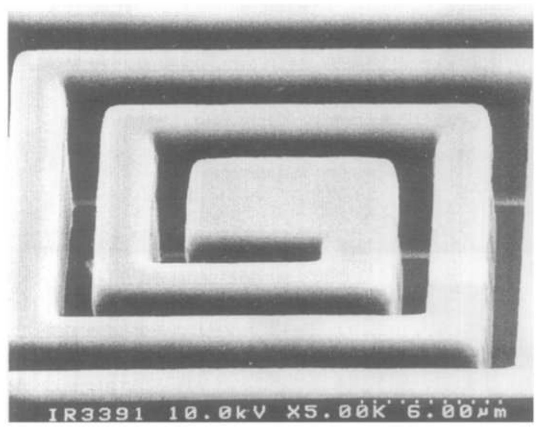

Fig. 8. Detail of fabricated silicon-open-stencil mask etched by gas chopping the BCl_3 gas flow in the gas mixture BCl_3/Cl_2 plasma [6] through ARCH.

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