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Abstract
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Keywords
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Effect of Developer Temperature on Photoresist Contrast in Grayscale Lithography

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I. Introduction

The contrast of a photoresist is one of its most important qualities; it describes the relationship between exposure dose and remaining fraction of photoresist left after development. While less important in optical lithography, where the exposure dose is usually set high enough to clear all exposed photoresist, it is very important in applications such as grayscale lithography. Research has shown that decreasing the temperature of the developer used can increase the contrast of the photoresist[1–3]. In this experiment, this relationship was tested in the opposite direction; the temperature of the developer was increased in an attempt to decrease the contrast of the photoresist.

II. Experiment

The first step of the fabrication process was to spin coat 2.5 microns of SPR 220-3 photoresist onto a four-inch silicon wafer and verify the initial photoresist depth using reflectometry. Next, the wafer was exposed using the Heidelberg DWL 66+ Laser Writer. The pattern used in this experiment was an array of 20 squares, with the laser power increasing in steps of 5 mW per square from 5 mW up to 100 mW. Three arrays of 20 squares were exposed onto one wafer, which was allowed to rest for 15 minutes to prevent carbon dioxide bubbles from forming before being baked at 115°C for 60 seconds. The wafer was then diced into three chips, each chip containing one array of squares, so that the chips could be developed at different temperatures. AZ300MIF developer was used for 60s with gentle manual agitation of the submerged chips. A hot plate was used to heat the developer and a thermocouple was used to check the developer temperature. The first chip was developed without any applied heat: the measured temperature was 19.3°C. The second and third chips were developed at 29.3°C and 39.3°C, respectively. After developing, profilometry was used to measure the fraction of remaining photoresist across the arrays on all three chips.

III. Results and Discussion

After characterizing the chips using profilometry, the contrast curves showing exposure laser power versus depth of photoresist cleared were plotted in Fig. 1.

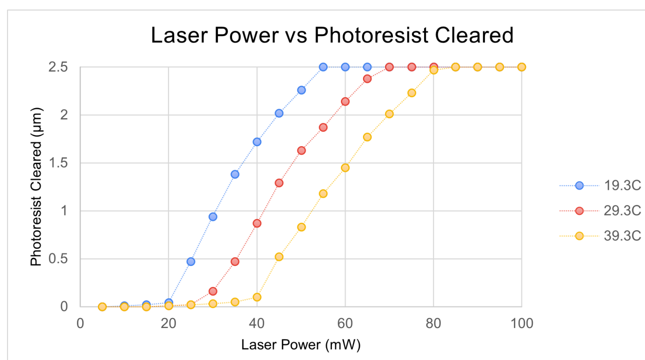

FIG. 1. Graph of Laser Intensity vs Photoresist Cleared for three different development temperatures

The predicted result, higher developer temperature leading to lower photoresist contrast, was indeed borne out by the data: the photoresist contrast decreases as temperature increases. At a developer temperature of 19.3°C, the contrast curve slope was 0.070 um/mW; this slope decreased to 0.064 um/mW at 29.3°C and dropped still further to 0.059 um/mW at 39.3°C. This data is compiled in Table 1.

Another result that was observed was that a higher developer temperature led to a greater laser power needed to clear the same amount of photoresist. For example, the chip developed at 19.3°C had all of its photoresist cleared at a laser power of just 55 mW, while the chips developed at 29.3°C and 39.3°C needed laser powers of 70

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TABLE I. Photoresist Contrast Curve Slope vs Development Temperature

Contrast Curve Slope (um/mW)	Temperature (°C)
0.070	19.3
0.064	29.3
0.059	39.3

mW and 85 mW respectively to clear all their photoresist. This result is in agreement with a paper by Chris Mack et al. which states "Development rate varies in a complicated way with temperature, usually resulting in the counter-intuitive result of a "faster" resist process (i.e., a process requiring lower exposure doses) at lower developer temperatures."[4] The described phenomena was observed in this experiment; lower exposure doses were required at lower developer temperatures.

IV. Conclusion

This experiment set out to prove that it is possible to decrease the contrast of a photoresist by increasing the temperature at which it is developed. Three chips were exposed using grayscale lithography, developed at different temperatures, and characterized using profilometry. The data showed that increasing developer temperature had two effects: the photoresist contrast was decreased, and a greater laser power was needed to clear the photoresist. There is a lot of room for further research in this area, including testing different photoresists and developers at different temperatures to determine their contrast curves. Heating the chip or wafer instead of the developer is another method that could be tested, and more research could determine whether heating the wafer or developer (or both) is most effective in decreasing photoresist contrast.

V. Acknowledgements

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