Comparison of Positive Tone vs. Negative Tone Resist Pattern Collapse Behavior

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In order for integrated circuit fabrication to continue to advance towards the 32 nm node and below, critical issues such as the pattern collapse of nanoscale features must be addressed. Understanding the differences in the collapse behavior of positive and negative tone systems and the various modes of pattern collapse including beam bending/breaking and adhesion failure could allow us to more efficiently develop methods to ultimately prevent pattern collapse. In this work, e-beam lithography patterns have been specifically designed which provide the opportunity to probe the collapse behavior of both positive and negative tone systems. Our pattern layout includes adjacent parallel line structures that both vary in the line size and also in the distance by which they are separated by the space between them. This type of structure allows for the control and modulation of the capillary forces, and ultimately the stress, experienced by the photoresist line pairs during the final rinse step of the development process (Figure 1). Using such structures, it is possible to determine the critical stress, i.e. the maximum stress experienced by the photoresist lines before collapse, as a function of a variety of parameters including: material type, substrate preparation conditions, resist film thickness, and resist feature width. In this paper, such a modular approach has been used to compare the pattern collapse behavior of a hydroxystyrene-based positive tone copolymer (ESCAP-1) to a negative tone epoxide-based molecular photoresist (4-EP). It was found that the critical stress decreased both as the thickness and the feature width of the resist line decreased, though this trend was observed to a much lesser extent in the negative tone 4-EP material (Figure 2). Preliminary results show that the 4-EP exhibited superior patterning performance as the photoresist lines could withstand much higher stresses relative to the ESCAP-1 at the thicknesses measured. This is likely due in a large part to the nature of the imaging mechanism in these materials, which in the case of 4-EP is based on crosslinking the material to form high molecular weight networks. Additional resists, including PMMA which operates by a chain scission mechanism and SU-8 as a negative tone comparison, have been studied and compared to these two material systems and will also be presented and discussed. Using a beam bending and deformation model, the moduli of the resists were also estimated as a function of both feature width and film thickness. The resist moduli have also been characterized independently using thin-film buckling experiments. These moduli data will be presented and the implications of this behavior for pattern collapse resistance of both positive and negative tone materials will be discussed.

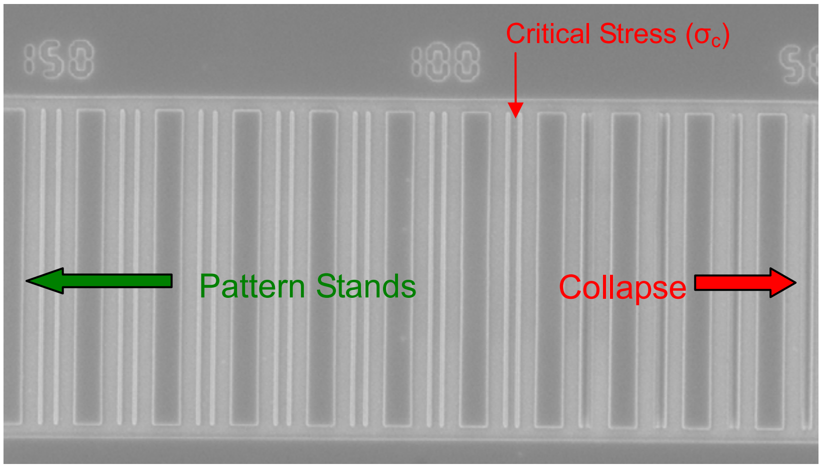

Figure 1. E-beam lithography pattern demonstrating pattern collapse and the point at which the critical stress is measured.

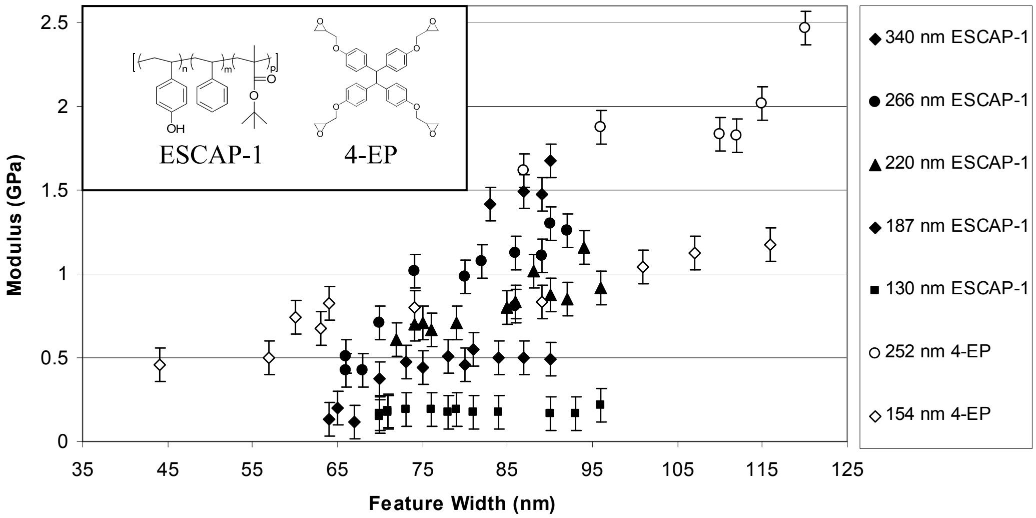

Figure 2. Critical stress as a function of feature width for various thicknesses of ESCAP-1 and 4-EP.