Lithographic Performance of The First Entirely Dry Process for EUV Lithography

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The lithographic performance of a new entirely dry EUV photoresist platform will be described. Photoresist films are applied using reactive organometallic precursors in a vapor phase process that provides uniform, homogeneous films stable to air and visible light. EUV exposure and subsequent bake steps induce crosslinking and densification, while unexposed areas remain hydrophobic and freely soluble in common organic solvents. This has facilitated the extensive characterization of lithographic patterning performance using NXE-3400 tools at both IMEC and ASML – initially employing conventional (solvent based) negative tone development (NTD).

In contrast to typical spin-on processes, dry deposited film thickness appears insensitive to substrate surface chemistry, making applied film thickness easily controlled/proportional to deposition time. EUV dose requirement (dose to size, or DtS) to print 16nm HP lines (in 32nm P dense l/s patterns) was ~45 mJ/cm^2 showing surprisingly little sensitivity to film thickness between 10nm and 25nm. A baseline (20nm thick) resist film patterned on the NXE-3400 resolves 13 nm HP L/S at a dose of 48 mJ/cm^2 and LWR of 2.7nm, translating to a Z-factor of 0.77, results roughly on par with those reported for leading edge spin-on metal oxide formulations. Full wafer CD uniformity of the baseline process measured at 16nm HP gave a 3σ of 2.4%, with an in-lot stability/variability of less than 1 mJ/cm^2 3σ DtS.

Significantly improved performance, particularly apparent at 13nm HP, is enabled using a new dry etch process -selective for unexposed films for pattern development. Key benefits can be attributed to the avoidance of capillary forces associated with solvent evaporation from between fine features. Full wafer FEM comparisons (over a large dose range) of identical dry deposited resist films (developed using wet vs. new dry etch technology) demonstrate an enormous increase in pattern collapse free process window. For example, dense underexposed features exhibiting CD values well below target (i.e. 10 nm vs. 13 nm) remain

standing and intact using dry development but are absent due to delamination or collapse at identically exposed die/patterns following solvent development. Additional benefits include reduced LWR and Z factor, together with cost and environmental advantages linked with eliminating liquid developers.
By combining vapor phase deposition and dry etch development, this new resist platform provides the first entirely dry (organic solvent and developer free) lithographic process applicable to high volume EUV manufacturing. Finally, extendibility down to 9nm HP was been demonstrated by exposures performed on the 0.5 NA micro-field exposure tool (MET5) at Lawrence Berkeley National Laboratory.

Presenting Author

Tim Weidman received his Ph.D. (focusing on Organometallic Photochemistry) from U.C. Berkeley in 1986. He spent the following 11 years at AT&T Bell Laboratories developing both "wet" and dry (plasma) based approaches to new organosilicon materials, and performed an early demonstration of dry DUV lithography based on the photo-oxidative patterning of plasma polymerized organosilicon hydrides. Moving back west – first to Applied Materials and later Sunpower, he spent the next 20 years leading a wide variety of programs applying new chemistry and hardware to leading edge semiconductor device or high efficiency solar cell fabrication. In 2017 he moved to Lam Research, where as Senior Technical Director he is focused on developing high performance process technology for all dry EUV lithography.