Rapid prototyping of etch test structures for hard mask development using electron beam lithography

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There is a need to screen novel hard mask (HM) materials still under development in a rapid fashion, yet traditional EUV manufacturing systems require 300mm wafers to be used. Here, electron beam lithography (EBL) is used as a proxy for EUV to generate nanoscale patterns in a maskless, direct write manner that mimic sub 50nm EUV features. Compared to EUV or other optical lithography means (DUV or Immersion), EBL provides larger freedom to create lithographic patterns of various sizes, pitch, and areas on substrates of different sizes (from large wafers to mm sized coupons) as a mask is not required. This allows for faster integration and characterization of test HM materials which are still under early phase screening, and which are prepared in small chamber tools and are not ready to be scaled up to a 300mm process. The primary goal of this work is to rapidly generate sub 44nm half pitch contact holes structures with EBL on coupons to provide a test structure for preliminary screening of new HM materials and etch chemistries. By comparing post etch performances at the smallest features for the different materials, it is possible to speed up the learning cycle and more rapidly decide which candidates will be able to satisfy a 300mm EUV scale up process.

Table 1 presents a summary of key challenges and issues that arise from rapid prototyping a standard test process from 300mm-wafer EUV to a coupon-size using EBL. As presented, transitioning a process from an existing 300mm process to a coupon scale EBL process is non-trivial. While all the listed issues require a solution for successful adoption of EBL, some innovative tricks were introduced. For example, microloading effects[1] on small coupons were mitigated via novel, diagonal arrays, while the notorious low etch resistance of EBL photoresists was mitigated using short, HBr cures[2]. For each challenge, we will offer a deeper dive into each optimized solution. Figure 1 presents the final etched product demonstrating that EBL can act as a proxy for EUV lithography on a full wafer scale. However, novel post-patterning techniques are required to satisfy tight downstream process restrictions (such as resist thickness, etch resistance, etch rate, feature uniformity). This process will greatly help with acceleration of evaluation of novel HM materials and can be extended to other pattern geometries, materials, and stack integrations in semiconductor technologies.

1 Shih-Ming Chang, Chih-Cheng Chin, Wen-Chuan Wang, Chi-Lun Lu, Sheng-Chi Chin, and Hong-Chang Hsieh, *Study of loading effect on dry etching process*. (SPIE, 2003).
2 Erwine Pargon, K Menguelti, M Martin, A Bazin, O Chaix-Pluchery, C Sourd, S Derrough, T Lill, and O Joubert, Journal of applied physics **105** (9), 094902 (2009).

Table 1. Lithography process restrictions for 300mm EUV and coupon EBL processes

Process Restriction	**300mm EUV**	**Coupon-size EBL**
Macroloading	Yes	No
Microloading	No	Yes
Proximity effects during patterning	No	Yes
Surface charging during patterning (function of tool mechanism and substrate stack)	No	Yes
CD non-uniformity (photoresist)	Yes	Yes
Etch resistance of photoresist	No	Yes
Write time (function of area)	No	Yes
Mask	Yes	No

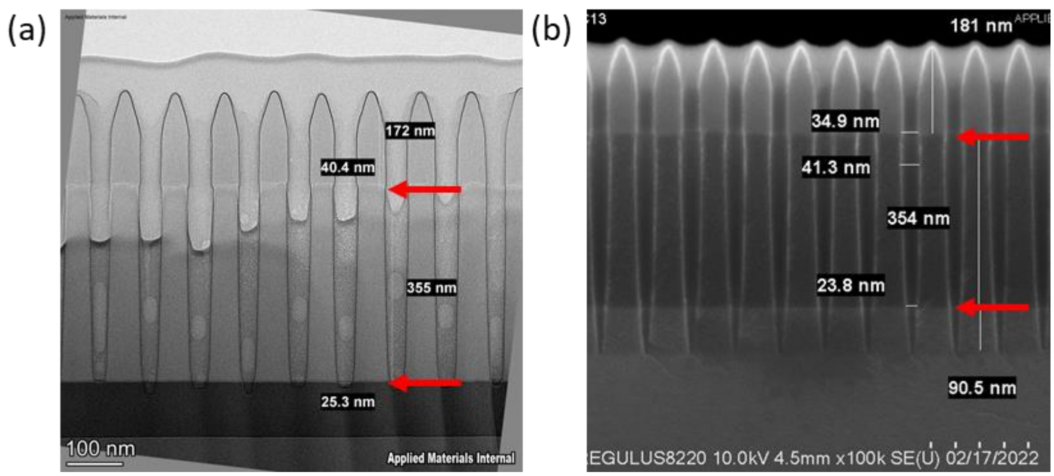

Figure 1. Full stack validation of (a) EBL patterned coupons against (b) EUV patterned coupons. The red arrows indicate the top and bottom of the test HM layer. Final post-etch dimensions of the HM are comparable: 40.4 nm post EBL vs. 41.3 nm post EUV at the top of the HM layer, 25.3 nm post EBL vs 23.8 nm post EUV at the bottom of the HM layer. The slight variation in post-etch dimensions can be attributed to etch chamber drift.