Measuring Pattern Quality and Porosity of Dielectric Insulator Films Directly Patterned by Nanoimprint Lithography

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Directly patterning interlayer dielectric (ILD) materials via nanoimprint lithography has the potential to simplify fabrication processes and significantly reduce the manufacturing costs for semiconductor devices.[1] However, the industry will soon demand ILDs with an ultralow-dielectric constant (ultra low-k. $k<2.3$) for their next-generation technologies. The prospect of mechanically forming these materials into nanoscale features, especially in their porous form, raises concerns regarding their physical integrity and pore structure. We report the first direct imprinting of sub-100 nm features into a high modulus poly(methylsilsequioxane) (PMSQ)-based resin creating nanoporous ILD patterns. In this presentation we show that patterns within a mold can be replicated with very high fidelity into these materials and that this fidelity is maintained during the high temperature vitrification process as the precursor materials are fully converted into a hard organosilicate. Specular X-ray reflectivity (SXR) and critical dimension X-ray scattering (CD-SAXS) [2] are used to quantify the fidelity of this pattern transfer process. Figure 1 shows quantitative profiles of the pattern cross-sections for the imprinted patterns, both with and without porogen. Immediately after imprinting the profiles are identical, irrespective of the porogen content. After vitrification a small amount of pattern shrinkage occurs relative to the mold. However, this shrinkage is anisotropic, primarily the limited vertical direction (and slightly greater in the porous sample); there is little change in the pattern width. X-ray porosimetry (XRP) and positron annihilation lifetime spectroscopy (PALS) measurements are then used to characterize the porosity of the patterned materials, as shown in Figure 2. Two populations of pores are observed in these materials, intrinsic microporosity native to the organsilicate and slightly larger nanopores induced by the porogen. Imprinting appears to decreases the population of mesopores associated with the porogen while enhancing the intrinsic microporosity. There is also evidence for the formation of a dense skin on the surface of the patterns. From the application point of view this is extremely attractive because it reduces the interconnectivity of the porous network and enhances barrier properties.

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[1] M. D. Stewart and C. G. Wilson, *MRS Bulletin* **30**, 947 (2005).
[2] H.-J. Lee *et al.*, *Appl. Phys. Lett.* **87**, 263111 (2005).

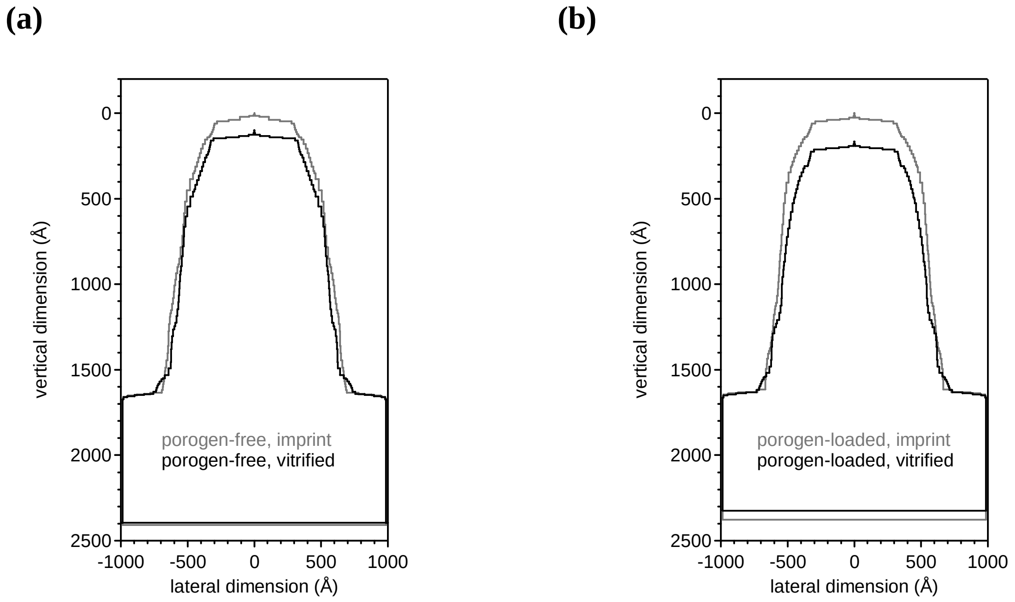

Fig 1. The quantitative profiles of the pattern cross-sections of the as-imprinted patterns for both the (a) porogen-free and (b) porogen-loaded sample are shown. The pattern shape change upon vitrification for the same two patterns also depicted indicating vitrification induces very minimal shrinkage in the lateral direction.

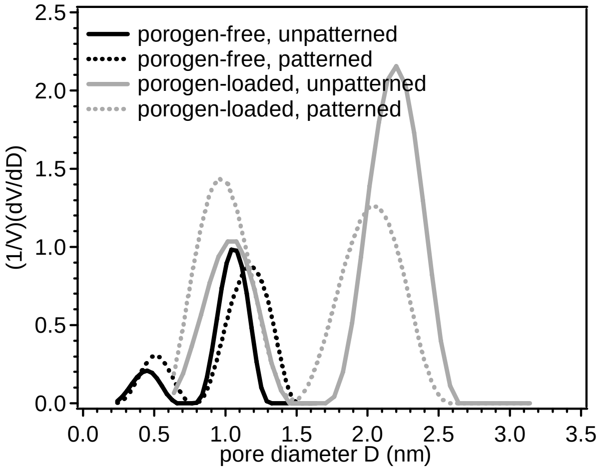

Fig 2. The pore size distributions of the four dielectric films fitted from the PALS spectra acquired at 2.7 keV using the CONTIN program are shown. The area under the PSD curve scales with the XRP measured porosity of the entire film for unpatterned films and the residue layer for the patterned film.