Bi-Level Micro- and Nano-Patterning of Functional Electronic Oxides

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Traditionally, the lithography and semiconductor industries have focused on doing the same with less, trying to keep essentially the same core functionality with less material as feature sizes are driven smaller and smaller. A complementary approach is to try to do more with the same, in other words to impart increased functionality at a given feature size through the integration of materials having increased intrinsic functionality.

Chemical solution deposition is a versatile approach to fabricating a wide variety of functional materials; of particular interest are high permittivity oxides such as TiO_2 and ferroelectric and piezoelectric oxides such as $BaTiO_3$ and $Pb(Zr,Ti)O_3$. Solution-derived $Pb(Zr,Ti)O_3$ films, for example, have been made to be continuous and functional as thin as 9 nm,[1] and have been shown to maintain their ferroelectric and piezoelectric properties following a microscale liftoff patterning technique (Fig. 1). Current approaches for achieving patterned features of such functional complex oxides generally involve deposition of a continuous layer of the oxide, thermal processing, then removal of unmasked regions of the oxide through wet and/or dry etch processes that leave significant regions of etch damage which provide a practical limit to achievable feature sizes for functional materials with excellent electrical performance.

Nanopatterning mediated by the directed self assembly of block copolymers has been repeatedly demonstrated as a powerful approach for creating well-ordered features at and below the 20 nm level, but only recently has this approach been extended to materials systems beyond Si/SiO_2.[2] Using a photo-patternable robust neutral brush layer that is compatible with a wide range of surface chemistries, we have been able to demonstrate the directed self assembly of columnar PS-b-PMMA onto a wide variety of materials including acidic and alkaline oxides, noble metals, transition metals, and conductive non-oxides (Fig. 2). Spin depositing a solution over such patterned masks enables liftoff deposition of solution-derived nanofeatures in patterns defined by the copolymer mask (Fig. 3). In combination, these techniques give us tremendous flexibility in the range of patterns that can be formed, the types of materials that can be patterned, and the substrates available for use.

[1] Sigman *et al.*, J. Am. Ceram. Soc., 91(6), 1851 (2008).
[2] E. Han, *et al.*, Adv. Mater., 19(24), 4448 (2007).

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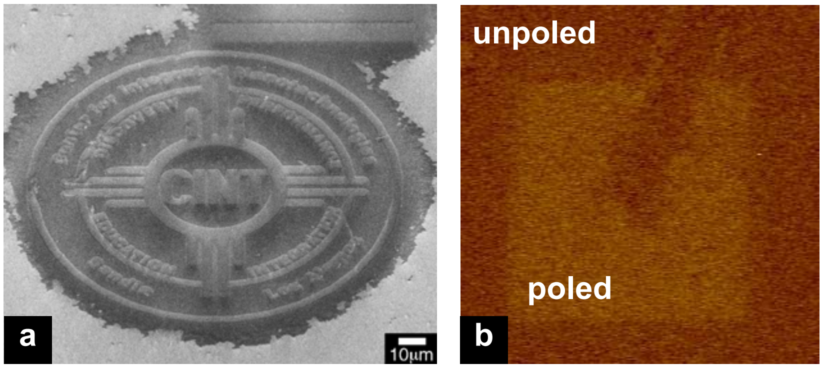

Figure 1 – PZT films patterned via MgO-mediated e-beam lithography maintain their ferroelectric characteristics.

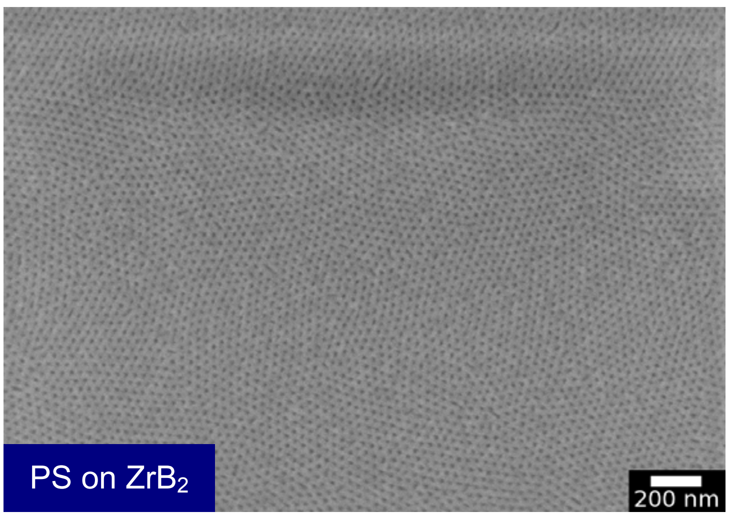

Figure 2 – PS-PMMA columnar structures patterned on ZrB_2 using a neutral brush layer.

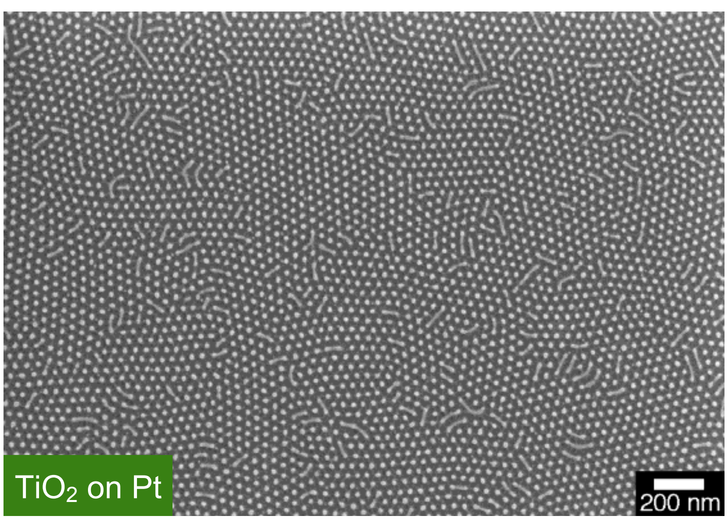

Figure 3 – Solution-derived TiO_2 nanofeatures on Pt after removal of the PS mask