ADDITIVE FABRICATION OF INTEGRATED MULTILEVEL THIN FILM MICROSTRUCTURES USING PRINTED THIN-FILM TEMPLATES

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Self-assembled monolayers (SAMs) of organic molecules, such as octadecyltrichlorosilane (OTS), have evolved as a new class of thin film materials with exciting prospects for applications in materials chemistry. Contact printing is one novel method of depositing patterned SAMs. The structures of thin films of OTS formed by contact printing on Al and SiO₂/Si surfaces have been investigated by x-ray photoelectron spectroscopy (XPS), ellipsometry, reflection-absorption infrared spectroscopy (RAIRS), scanning electron microscopy (SEM), and atomic force microscopy (AFM). Figure 1 shows representative RAIR spectra in the C-H stretching region for OTS films on SiO₂/Si substrates as a function of OTS concentration. Samples were prepared either by (A) contact printing or (B) solution immersion for 30 s in each instance. The films formed by contact printing with an OTS “ink” are composed of close-packed, predominantly all-trans alkyl chains aligned nearly perpendicular to the surface. The layers obtained by immersion in solution are low coverage and conformationally disordered.

Figure 1

For the sample stamped for 30 seconds (Figure 2A), sharp boundaries between OTS derivatized (light regions) and undervatized (dark regions) areas were observed. Longer stamp times (60 s) result in broadening of the lines with resulting loss of the pattern fidelity (Figure 2B).

Figure 2

Reported applications of SAMs include the use of contact printed alkylsiloxane monolayers to direct selective deposition of metal thin films by CVD. Pure platinum and palladium thin films were selectively deposited by combining microcontact printing and metal-organic chemical vapor deposition (MOCVD). This process has been used to fabricate Pt and Pd patterns on substrates such as titanium nitride (TiN), indium tin oxide (ITO), SiO₂, and sapphire. Pattern features as small as 1.5 μm lines have been reliably deposited by this combined printing-MOCVD method. Figure 3 shows SEM images of (A) 3 μm wide Pt lines deposited selectively on SiO₂/Si, and (B) 1.5 μm wide Pt lines deposited selectively on TiN.

Figure 3

In addition, large area patterns have been accurately reproduced. Figure 4 is an optical micrograph of a large scale pattern of Pd selectively deposited on indium tin oxide (ITO).

Figure 4

Thin films of copper have also been patterned through the use of SAMs. By exploiting the weak interfacial interactions between the metal and a OTS monolayer, metal adhesion to the surface can be limited to regions unmodified by OTS. Nonselective CVD on a patterned surface followed by mild mechanical polishing gives high resolution patterns without resorting to chemical etching.

SAMs have also been used with sol-gel methods to pattern ceramic thin films on substrates. The patterning of ceramic thin films involves a lift-off process whereby the ceramic thin layers on SAM modified regions of the substrate delaminate while smooth, continuous films form on the unmodified regions, where adhesion is strong. The loosely adhered film above the SAM can be removed after calcination and mechanical polishing, yielding a patterned oxide layer (Figure 5).

398
This technique has been successfully demonstrated for a number of ceramics, including LiNbO$_3$ and (Pb,La)TiO$_3$, which have desirable dielectric properties. Figure 6 shows one such sample of (a) strip waveguides of LiNbO$_3$ with widths from 4 µm to 40 µm were patterned on Si, (b) illumination of patterned strip waveguides, 4 µm to 120 µm in width, of heteroepitaxial LiNbO$_3$ on sapphire, and (c) excitation of the TE$_0$ mode in 120 µm wide, 80 nm thick strip wave guide seen in (b).

Although single levels of thin films have been patterned with great success, significant obstacles must be overcome before it will be possible to fabricate useful devices that include precisely aligned multilevel patterns. Toward this end, an additive patterning technique based on printed organic thin films has been used to fabricate simple ferroelectric capacitors consisting of a Pt/PZT/Pt thin film structure. The printed organic thin films of OTS direct selective deposition of platinum by metal-organic chemical vapor deposition (MOCVD) and aid in patterning of sol-gel derived ferroelectric lead zirconium titanate (PbZr$_{0.53}$Ti$_{0.47}$O$_3$, PZT) thin films, enabling additive fabrication of the capacitors without photolithography or reactive ion etching (RIE). Figure 7 shows such a device, where the large circles are comprised of 1000 Å of Pt underneath 1000 Å of PZT, with additional, smaller dots of 800 Å of Pt on top.

REFERENCES


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