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Synthesis and patterning of nanostructures of (almost) anything on anything

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Nature has very stringent rules that govern nucleation and growth, but growth on a buffer layer makes it possible to circumvent those rules and fabricate a very wide range of nanostructured materials. By combining buffer layers and laser induced desorption, it is now possible to produce novel and potentially useful nanoscale patterns.

Keywords: Laser induced thermal desorption (LITD); Growth; Clusters

A necessary and very challenging condition for progress in nanoscience is being able to synthesize the requisite material. While there has been substantial success for some materials, one would like to develop protocols to fabricate structures of a wide variety of materials on an equally wide range of supports, preferably with size selection and the ability to pattern on large areas at low cost. The paper by Kerner and Asscher in this issue [1] is significant because it shows how at least some of those conditions can be satisfied in a novel and creative way.

Building on the techniques of surface science, many researchers have focused on physical vapor deposition and the subsequent assembly of 1D wires, 2D islands, and 3D clusters. The problem, of course, is that Nature provides rather stringent rules that prevent the spontaneous assembly of 3D structures for all but a few materials. In particular, 3D growth will occur only if the adatoms interact only weakly with the surface but strongly with one another, with details dictated by surface and interface energies.

A technique was developed a few years ago that by-passed these rules, termed buffer-layer-assisted-growth (BLAG) [2–4], and the paper by Kerner and Asscher combines this technique with laser induced thermal desorption to form patterns in a novel and potentially important way.

The idea behind buffer layer assisted growth is remarkably simple, as depicted in Fig. 1. The buffer layer replaces adatom–substrate interactions with very weak adatom–buffer interactions so that balling-up occurs out of contact with the substrate. The buffer must subsequently be removed so that the clusters are delivered in the ultimate of soft landings to the substrate where wetting is frustrated by kinetics. While there

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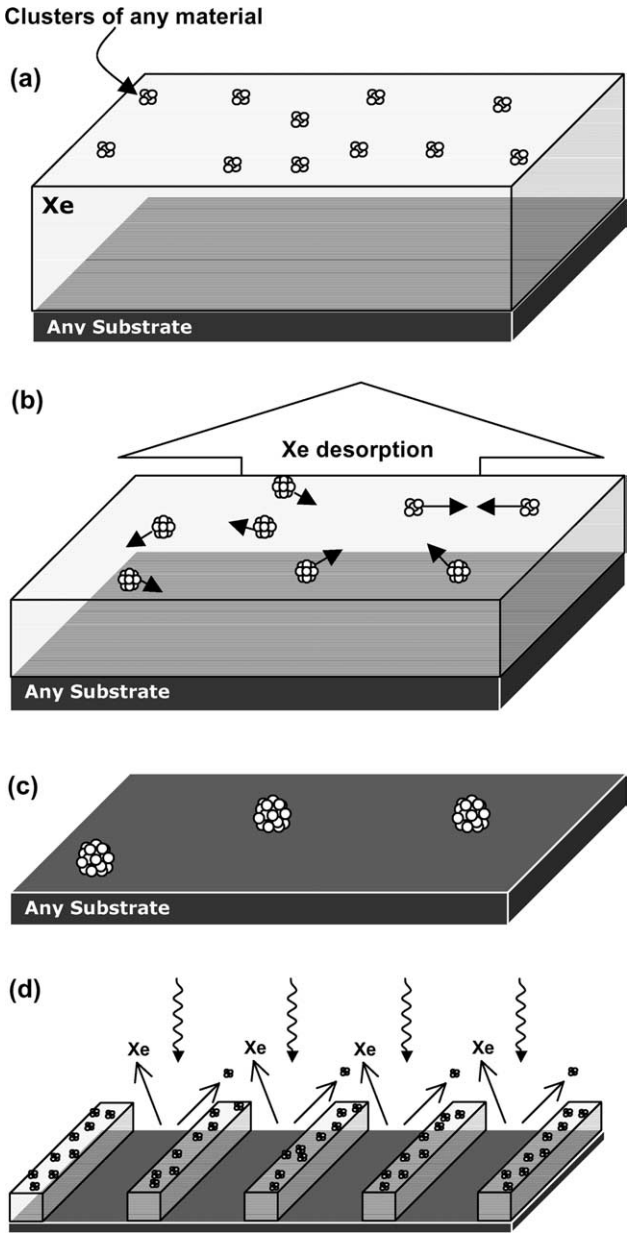

Fig. 1. Depiction of buffer-layer-assisted growth. (a) A support has been cooled to ~20 K and exposed to Xe from the gas phase to grow a protective layer on the support. Subsequent exposure of this surface to atoms evaporated from a hot source, for example, will allow condensation of those adatoms and their subsequent diffusion, even at low temperature. This produces 3D clusters. As indicated, this can be done with (almost) anything on anything. (b) The temperature is being increased so that Xe desorption occurs. This activates the motion of the clusters so that they aggregate and coalesce, all under ultrahigh vacuum conditions. (c) The Xe has completely desorbed and the clusters have been delivered to the substrate. The density of such clusters and their size can be controlled by varying the thickness of the buffer layer. (d) Kerner and Asscher modified the process by patterning the sample in (a). They used laser heating at the constructive interference regions of a split laser beam, causing selected-area ablation of the Xe and anything on it. Subsequent warm-up and Xe desorption delivers the nanopattern to the substrate. The pattern could be derived from isolated particles if the amount of material is small, but it could be continuous if the initial deposition is greater.

are several possible buffer materials, the one used most commonly is the rare gas Xe. It is convenient because it can be grown at ~20 K and desorbed by ~80 K, and it introduces no 'chemistry' in the process.

Multilayer films of Xe protect the substrate and represent a highly incommensurate surface on which atoms can diffuse and clusters can form. Moreover, as it desorbs its phonons activate cluster diffusion which leads to aggregation and coalescence. The result is that preformed structures can be delivered to a surface establishing nanostructures that cannot be fabricated in any other way. Moreover, the density of those structures can be varied over several orders of magnitude by changing the buffer layer thickness [4]. Recent studies by the Weaver group have focused on the stability of those structures, their bonding to the substrate, and the physics underlying nanoparticle diffusion and aggregation [3]. Work by Wendelken and coworkers [5,6] has emphasized growth of magnetic structures of Fe and amorphous Ge clusters.

What Kerner and Asscher did that was novel and exciting was that they adapted this technique to form metal wires on a surface. They knew that laser induced thermal desorption (LITD) was an effective way to pattern adsorbates on a surface but recognized that patterns of strongly bound adsorbates could not be formed without damaging the surface by laser heating. They reasoned, however, that multilayers of Xe could be patterned with LITD at laser intensities that were harmless for the substrate. Moreover, with a single pulse, they could remove not only the adsorbed Xe but also anything on top of it. At low temperature, therefore, they produced patterns with metal coatings on Xe on the substrate. As usual in BLAG, warming-up then desorbed the Xe and delivered the metal to the substrate, retaining a nanopattern of adsorbates that would be impossible to form by other means currently available.

As Kerner and Asscher note, work that combines BLAG and LITD has the potential of forming wires that are only ~30 nm wide but can be as much as 5 mm in length (aspect ratio 10^5). Such patterns can be made with strongly interacting adsorbate materials that cannot be produced in other ways, representing a significant step in nanofabrication. Those templates can be used as arrays for preferential chemisorption, as patterns for subsequent growth or reaction, as lines that passivate the substrate, and in studies of carrier transport in confined channels. The combination of BLAG and LITD is compatible with dry processing with stringent conditions on cleanliness and it can be used in large-scale patterning.

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