Template-Stripped Plasmonic Films for Thermophotovoltaics

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Abstract Summary: Template stripping is a simple and versatile process for creating smooth patterned films from various materials. We will discuss improved plasmonic performance for template-stripped metals and their use in thermophotovoltaic applications.

Introduction: Template stripping utilizes the fact that coinage metals (e.g., silver, gold, and copper) will wet certain substrates but adhere poorly [1]. This can be exploited to obtain ultrasmooth metal surfaces. For example, metal can be deposited on a polished silicon wafer and then covered with an epoxy adhesive as a backing layer. Because the adhesion between the metal and the silicon substrate is weak, the backing layer along with the metallic film can be easily peeled from the substrate. The metallic surface that is exposed replicates the smooth interface of the flat substrate. Thus, surface roughness as low as a few angstroms can be obtained. Such films have been heavily exploited by researchers in the fields of scanning probe microscopy and self-assembled monolayers.

Patterned Films for Photonics: Recently, it was recognized [2, 3] that a similar approach could be used to obtain ultrasmooth patterned films for photonic applications. In the field of plasmonics, metallic films are patterned to manipulate electromagnetic waves known as surface plasmon polaritons (SPPs) that exist at the interface of the metal. These waves can be channeled, concentrated, or otherwise manipulated by surface patterning. However, because surface roughness and other inhomogeneities can limit surface plasmon propagation in real devices, template stripping can provide a simple high-throughput method for obtaining high-quality patterned metals. Figure 1 shows examples of structures that can be obtained, including a bull's eye (left) and a pyramid (right). We have demonstrated that a large variety of such structures can be prepared with nanometer precision [4, 5]. In addition, sharp tips can be created that focus light into nanometer-scale volumes [6]. Because the patterned silicon template can be reused after the structures are released, the template-stripping approach provides a versatile strategy for creating many devices that are identical [3]. Thus, template stripping can be added to our tool kit of useful fabrication techniques for engineered structures for plasmonics and nanophotonics [7].

Improved Photonic Properties: Template stripping not only reduces surface roughness in metallic films, which results in reduced radiative scattering of SPPs, but it also improves

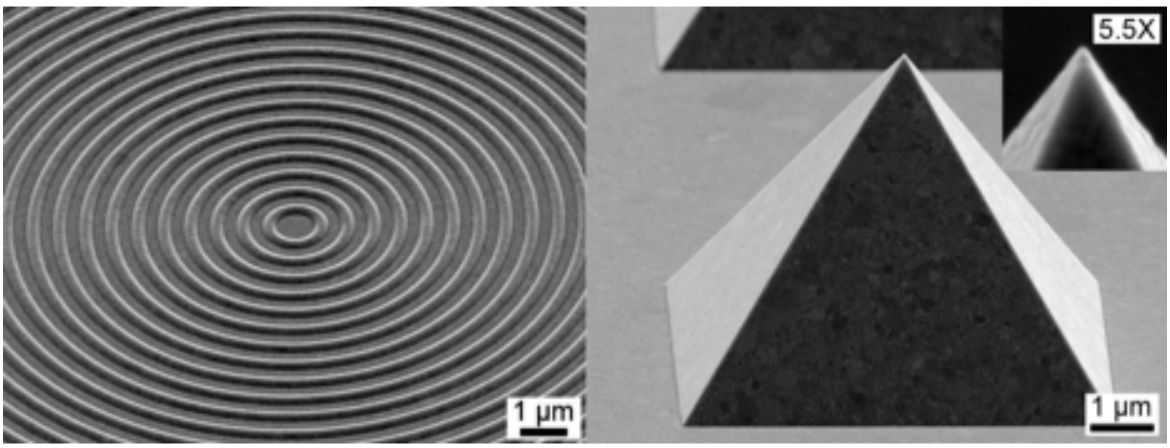

Fig. 1. Electron micrographs of a template-stripped Ag bull's eye (left) and pyramid with a sharp tip with a radius of curvature of 10 nm (right). Reproduced from [3].

several other important photonic properties. If the film is subjected to a mild thermal treatment before it is stripped off the substrate, the crystalline grains in the metal grow while still constrained by the substrate interface. After stripping, this results in larger grains that still maintain surface smoothness. The increased grain size can reduce grain boundary scattering, which is a loss mechanism for surface plasmon propagation. More importantly, template-stripped metallic films exhibit effective dielectric functions with a more negative real component and a smaller imaginary component, implying higher conductivity and less energy loss, respectively [8]. The improvement in the effective dielectric properties shows that template stripping can be a simple approach to high quality metallic films for a variety of photonic applications.

Beyond Coinage Metals: In addition to the coinage metals, this approach to patterned films can be extended. First, stacks of different layers can be combined, e.g. alternating layers of silver and alumina have been simultaneously stripped off patterned silicon substrates [3, 9]. Such multilayer metallodielectric structures can be useful for a variety of applications, including metamaterials and photovoltaics. Second, we have extended template stripping beyond silver, copper, and gold. Now a large variety of materials, including refractory metals, semiconductors, and oxides can be patterned [9].

Thermophotovoltaics: We have been exploiting patterned refractory metals to test the use of template-stripped films for thermophotovoltaic applications. Because heat can be used to generate SPPs, hot plasmonic structures can exhibit interesting optical behavior. For example, metallic bull's eye patterns can lead to thermal emission that is amazingly narrow, both in terms of its spectrum and its angular divergence [10]. Thus, a simple metallic foil can generate a highly directional beam of monochromatic light by a thermal process. This effect has implications for efficient thermophotovoltaic devices, which convert heat into electricity.

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