

**PROCESS FOR UV-PHOTOPATTERNING OF  
THIOLATE MONOLAYERS  
SELF-ASSEMBLED ON GOLD, SILVER AND  
OTHER SUBSTRATES**

**BACKGROUND OF THE INVENTION**

The present invention relates to a photopatterning process for controlling the two dimensional spatial distribution of molecules in thiolate self-assembled monolayers ("SAMS"), particularly alkylthiolate self-assembled monolayers, on gold, silver and other substrates.

Precise control of the spatial position of the thiol compound molecules on a surface would permit manipulation of the chemical and physical properties of selected areas of the surface to bind inorganic, organic, and biological molecules and species. The ability to bind biological species such as proteins, enzymes, DNA and cells at known locations on surfaces could be important for a variety of technologies including biosensing, immunoassay diagnostics, DNA probe diagnostics and sequencing, pharmacological and toxicological testing, and cell growth studies. For example, in the area of biosensing, the ability to pattern and immobilize multiple proteins on surfaces would allow the construction of miniaturized, multi-analyte sensors capable of operating in blood vessels or on a single cell. In the area of DNA sequencing, the ability to immobilize DNA probes on surfaces with  $\leq 10$  micrometer spacing would be a key step in the fabrication of a new generation of miniaturized DNA sequencers supported on micro-chips. The same monolayer patterning process could also be used to lithographically pattern the underlying substrate (gold and silver) through the use of chemical etching reactions to form individually addressable micro-electrodes that would be useful for many chemical sensing and diagnostic applications.

Two processes are currently known for patterning alkylthiol monolayers on compatible substrates. The first is a mechanical method such as disclosed by N. L. Abbott, J. P. Folkers, and G. M. Whitesides in *Science* 257 (1992) at pp. 1380-1382, whereby portions of the SAM are physically removed by impressing a scalpel or carbon fibers across or on the SAM sample. This method suffers from the disadvantages, however, that the use of physical force may deform and damage the sample and/or the expensive pattern mask. The second process is a photolithographic method disclosed in Frisbie et al., *Journal of Vacuum Science and Technology A*, Vol. 11, pp. 2368-72 (1993). This process requires that a specific photo-active functional group (an aryl azide) be incorporated in the alkylthiol molecules, and thus is not generally applicable to other alkylthiols.

**SUMMARY OF THE INVENTION**

Accordingly, an object of the present invention is to provide a photopatterning process for precisely regulating the two dimensional distribution of surface molecules in a SAM.

Another object of the invention is to provide a precise process for photopatterning SAMs which permits the formation of closely spaced features (line spacing less than 100 micrometers) therein.

Yet another object of the invention is to provide a photopatterning method that does not require physical contact with the sample, and thus does not deform the substrate.

Still another object is to provide a process that does not require the presence of a photo-active pendant group and is

therefore applicable to SAMs comprised of molecules of any compound capable of forming a thiolate SAM.

A further object of the invention is to provide a patterned biomolecular composite in which a biological material is adsorbed on a substrate in a controllable patterned arrangement.

These and other objects of the invention are achieved by providing a process for creating a pattern comprising a two dimensional spacial distribution of thiolate compound molecules in a self-assembled monolayer formed on a substrate comprising the steps of illuminating a surface of a self-assembled monolayer of a first thiolate compound in the presence of oxygen with high frequency electromagnetic radiation distributed according to a desired pattern; and immersing the substrate in a solution of a compound capable of producing a second thiolate compound, whereby molecules of the first thiolate compound in illuminated areas of the monolayer are exchanged for molecules of the second thiolate compound.

In accordance with a further aspect of the invention, the objects are also achieved by providing a patterned biomolecular composite comprising a substrate capable of forming a self-assembled thiolate monolayer when immersed in a solution of a compound capable of forming a thiolate compound; a thiolate monolayer deposited on the substrate, the thiolate monolayer comprising patterned areas composed of first and second thiolate compounds, respectively, wherein the first thiolate compound has an affinity for specifically or nonspecifically adsorbing a biological molecule, and the second thiolate compound has essentially no affinity for the biological molecule; and at least one biological material adsorbed in a corresponding pattern on the patterned areas of the thiolate monolayer composed of the first thiolate compound.

The patterning method according to the invention has been derived from two observations. The first observation is that when adsorbed alkylthiolate ( $RS^-$ ) molecules are irradiated with ultraviolet (UV) light in air, the molecules in the monolayer are oxidized to the corresponding alkylsulfonate ( $RSO_3^-$ ) molecules. The second observation is that alkylsulfonates are weakly bound to substrate surfaces, and are thus easily displaced from the SAM by subsequent immersion of the sample in a solution of a compound capable of forming a thiolate compound, such as an alkylthiol solution, a dialkyl sulfide solution or a dialkyl disulfide solution. The photopatterning method of the invention makes use of these two observations in combination.

A thiolate monolayer is first self-assembled on a gold, silver or other suitable substrate surface. A pattern of sulfonate molecules is then formed in the SAM by UV irradiation in air (e.g. using a high pressure mercury lamp) through a mask. The mask can be placed directly on the sample or can be imaged on the sample using appropriate optics. The UV light in the presence of oxygen causes a photo-oxidation reaction to occur, whereby the thiolate headgroups are converted to sulfonate functional groups. After UV exposure, the sample is then immersed in a dilute solution of a different thiol compound. The sulfonate molecules in the exposed areas of the original SAM are displaced, incorporating the second type of thiolate compound into the monolayer. This process results in a single monomolecular film composed of molecules of two types of thiolate compounds in a pattern determined by the mask.

Pattern features in the SAMs of approximately 10 micrometers have been demonstrated on gold and silver substrates using the process according to the invention.