Nodal Lithography: Resist for optical patterning below the diffraction limit

K.M. Rosfjord, S.E. Kooi, A.C. Chao, K.K. Berggren
Massachusetts Institute of Technology, Cambridge, MA 02139

Conventional optical-lithography schemes are resolution limited. Here we propose a new lithographic method, nodal lithography, which does not have this limitation. Nodal lithography uses the nodes of an optical field to make a pattern on a substrate. This is done with two optical pulses. The first pulse causes an optical excitation of molecules creating a highly reactive short-lived state everywhere across the surface. Then a patterned pulse quenches the molecular excitations everywhere except at the nodes of this second pulse. At the nodes, a chemical reaction of the excited state molecules occurs, creating a pattern in the resist. This exposure sequence is illustrated in figure 1. As the nodes of the quenching field define a singular point in space, the feature size can, theoretically, be made arbitrarily small by increasing the quenching field intensity. The resist molecules not at the optical node are restored to the ground state after each laser-pulse cycle. This enables these molecules to be exposed in subsequent steps as well as to be exposed in parallel.

In addition to having the traditional properties of a resist, a nodal lithography resist must demonstrate absorption and emission in a predetermined part of the spectrum as well as a relatively long lifetime in order for the exposure scheme to be successful. We tested a photopolymer resist comprised of a urethane acrylate oligomer (CN997), alpha hydroxyl ketone photoinitiator (Esacure ITX) and co-initiator (Esacure EDB), and solvent (MIBK) mixture that exhibits strong potential as a nodal lithography resist. The oligomers of the mixture serve as the backbone of the photoresist, and undergo polymerization into a hard surface after reacting with an excited photoinitiator. This mixture has been tested to determine approximate dose requirements for exposure and a developer has been identified. Figure 2 displays the absorption and emission spectra of the resist. Fluorescence lifetime measurements on a thin film of the resist spun onto a glass slide resulted in a bi-exponential decay of 1.1 and 3.3 ns. This slow decay time is within the timing capabilities of our system for quenching, thus making this mixture a promising candidate as a nodal lithography resist.

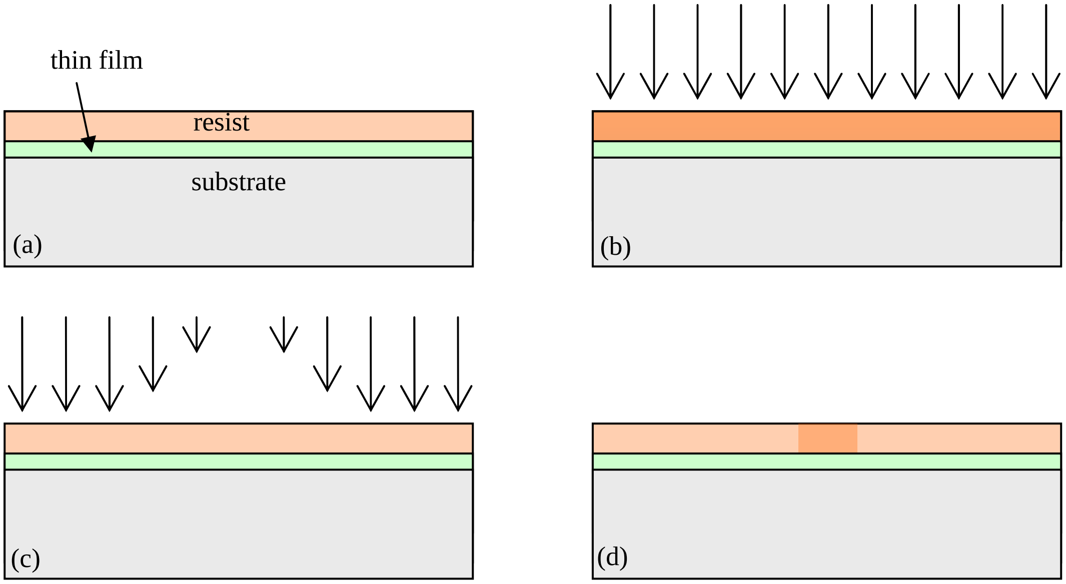

Figure 1. Nodal lithography exposure sequence: (a) begin with a resist on top of a film to be patterned, (b) next the resist is uniformly excited, (c) then the resist is selectively quenched by a patterned optical field, (d) lastly the excited molecules react. As the molecules not at the node are restored to the ground state after each excitation and quenching cycle, these molecules may be excited (ie. patterned) in subsequent steps.

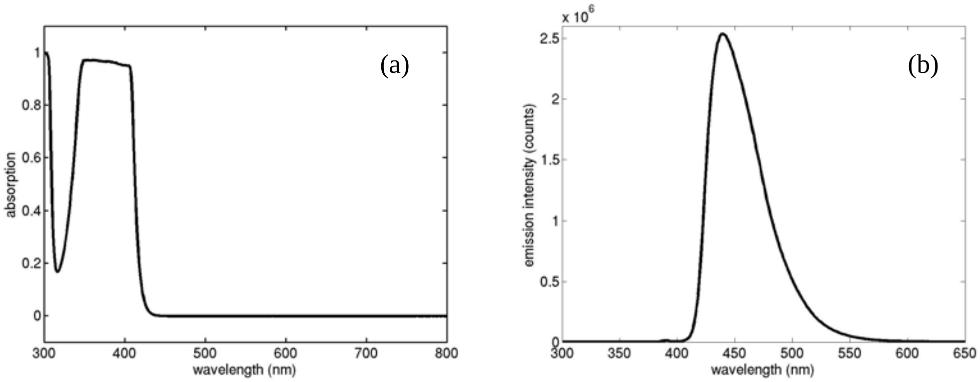

Figure 2. (a) absorption and (b) fluorescence emission spectra of Esacure ITX initiator in methanol. The emission spectrum was found with an excitation wavelength of 390nm.