Preparations of Nanostructures I:
Next Generation Lithography

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Abstract

The main use of lithographical technologies today is the production of logical and memory integrated circuits found in every modern electronic appliance. These structures already qualify as nano scale structures as their critical dimensions are smaller than 100 nm – today's transistors used in mass produced CPUs already reach a gate length of down to 45 nm. Following Moore's Law that proposes a multiplication by two of the complexity of integrated circuits every 18 months and a reduction of the critical dimension to one half respectively, the chip making industry and the associated solid-state physics research has to go great lengths to ensure the next technology step within a given time frame. Years ago, even the possibility of sub-micron technology was disputed. Today only the atomic monolayer scale sets a final limit to lithography and will require a new approach to increasing computer power before 2020.

The basic principle of optical lithography has remained unchanged for decades: a silicon wafer is coated with a light sensitive polymer, the so-called resist, that can be removed upon exposure to light, enabling access to defined areas on the wafer. This step is repeated 20 to 30 times in order to create several layers of structures on the wafer. The size of the structures that can be written onto the wafer are defined by the quality of the used optics, i.e. the light source, the mask that bears the structures on it and the lenses that project a picture of the mask onto the wafer. The possible resolution of an optical apparatus is described by the Raleigh criterion: $W = \frac{k\lambda}{n\sin\theta}$, where W is the structure size, k is an empirical constant, λ is the wave length of the used light source, n is the refractive index of the medium the light passes through and θ is half the angle of the optic's aperture. A first approach to enhance the resolution is to tweak the optics. This is realized by phase-shift-masks and proximity corrections, enhancing the resolution by improving only the masks. But significant reduction of critical dimensions can sooner or later only be achieved by reducing the wavelength.
A first step in this direction was the intended use of 157 nm lasers instead of 193 nm. However the materials challenge of producing the required optics at low cost and high yield could not be resolved. A soon to be realized approach is the use immersion technology, where a water droplet is introduced between the optics and the wafer, thus increasing n. Using water instead of air creates many technological challenges that probably will be resolved by mid 2006. AMD and IBM plan to introduce this technology, Intel claims to use the current technology down to 32 nm.
A huge step forward will be the commercial use of extreme ultra violet light sources probably starting in 2009. A gas discharge or laser driven plasma will deliver light at 13.5 nm. The optical system has to consist of mirrors, as no transparent materials exist at this wavelength. Demonstrator tools already exist but they cannot achieve lifetime and throughput necessary for commercial production. Alternatives to EUV have been ruled out due to various problems, e.g. x-ray (use of prohibitively expensive synchrotrons as light source), electron beams

(serially scanning the waver and thus extremely slow), electron projection (defocusing itself) or ion beams (lacking power).

Nano imprint is a different approach to lithography as it uses pressure and temperature or pressure and UV light to mechanically print the surface of a mold onto a substrate. It lacks the necessary throughput and refinement for a use in commercial chip production but could be useful for different nano scale structures like micro fluidics. However nano imprint can’t stand on its own, as it still requires a different technology for production of the template at 1:1 scale of the required structure.

Two-photon lithography leads the way to creating three-dimensional structures with lithography. Using a light source at half the necessary wavelength to initiate the polymerization process of the resist, only molecules that absorb two photons at a time are affected by exposure to light. The probability of photo initiation now decreases drastically with distance from the laser’s focal point compared to regular lithography, allowing modification of the structure in a small three-dimensional volume around one discrete point. Basically any desired three-dimensional connected structure can be created with critical dimensions being at about 250 nm today.