

Immersion Lithography

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Term “resolution” defines precision with which lithographic process transfers patterns from the mask to the layer of photoresist. Numerically, higher resolution of the lithographic pattern transfer process is expressed by lower numbers in terms of nanometers representing minimum feature size that can be exposed. In the simplest way it can be defined as follows:

$$\text{Resolution (nm)} = k_1 \lambda / \text{NA} \quad (1)$$

where k_1 is the process factor representing variables of the photolithographic process, λ is the wavelength of radiation used for exposure, and NA is the numerical aperture of the lens system expressed as

$$\text{NA} = n \sin \Theta \quad (2)$$

where n is the refractive index of the medium between the lens and the wafer through which the exposure radiation passes, and Θ an angle reflecting lens ability to focus light passing through it (Fig. 1b). As seen in this figure increase of Θ from Θ_2 to Θ_1 results in the better resolution of the pattern transfer, i.e. smaller geometrical feature can be exposed at the same angle of incidence.

Since the beginning of modern semiconductor device technology, desired increase of the resolution of the pattern transfer process by means of optical lithography (photolithography) was relying on the gradual reduction of λ by switching to shorter λ UV sources. For instance, almost 20x increase in resolution (20x smaller features could be patterned) was achieved over the years by reducing wavelengths from $\lambda = 436$ nm (g-line in the mercury lamp spectrum) to $\lambda = 193$ nm produced by argon fluoride (ArF) excimer laser.

As the reduction of λ in the UV spectrum below 193 nm is technically challenging (lack of adequate UV sources) attention is also focused on the ways of increasing resolution by increasing numerical aperture NA. As Eq.(2) suggests, NA will increase when the index of refraction of the medium through which the exposure radiation passes between the lens and the wafer will be increased from $n = 1$ for air (exposure is carried out in air) to, for instance, $n = 1.44$ for ultra-pure de-ionized water. It is this reasoning that laid ground to the introduction of “immersion lithography” into high-end semiconductor device manufacturing.

Basic layout of the immersion projection lens system is shown in Fig. 1. The difference between conventional projection lithography and immersion lithography is that the resist is exposed by the light

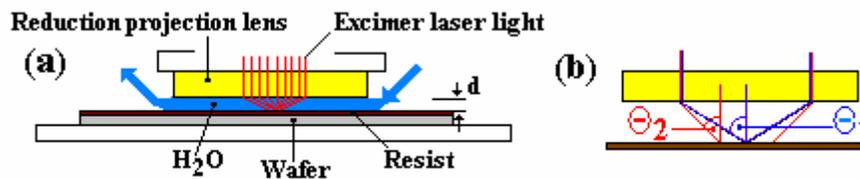


Fig. 1

passing through a thin layer of ultra-pure water (distance d is typically in the millimeter range) rather than through air. The key challenge of this approach is to maintain supplied water perfectly contamination-free and bubble-free for each and every exposure run.

Further progress can be accomplished by switching to liquids displaying n larger than $n=1.44$ for de-ionized water. For instance, non-aqueous solutions based on organic fluids and featuring n in the range 1.5 – 1.8 would result in the so called hyper-NA lens systems ($\text{NA} > 1$). With such systems resolution in the range of 35 nm should be possible using ArF excimer laser for exposure ($\lambda = 193$ nm).