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NON-LINEARITY OF THE DISSOLUTION BEHAVIOUR IN EUV PHOTORESISTS

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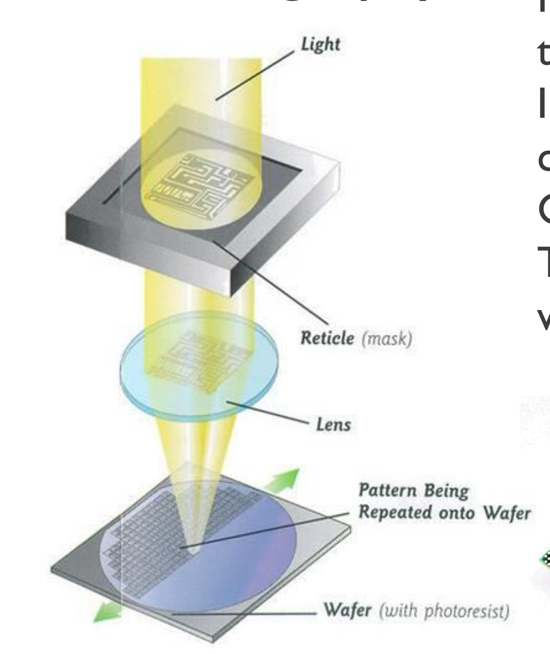
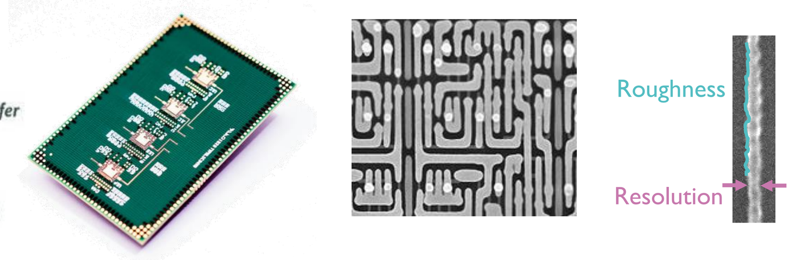
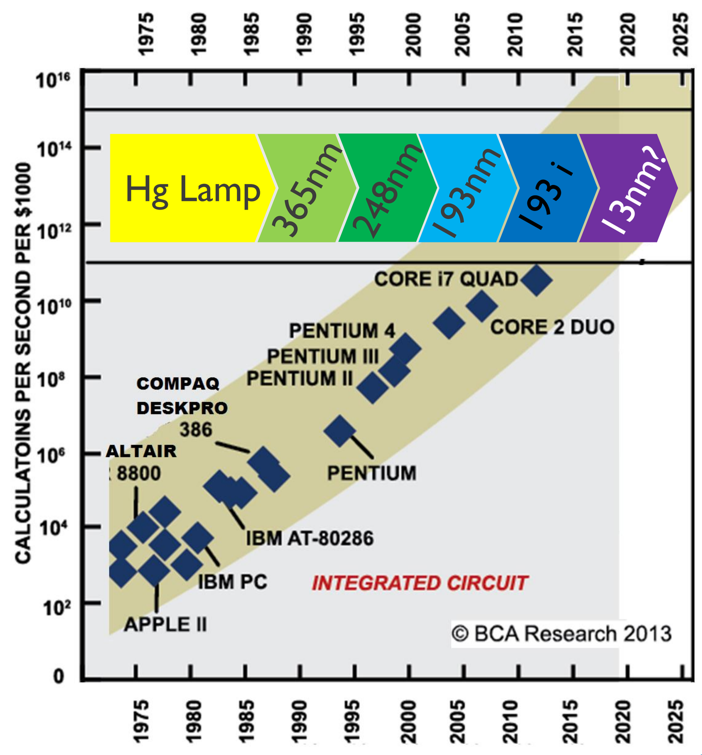
Photolithography



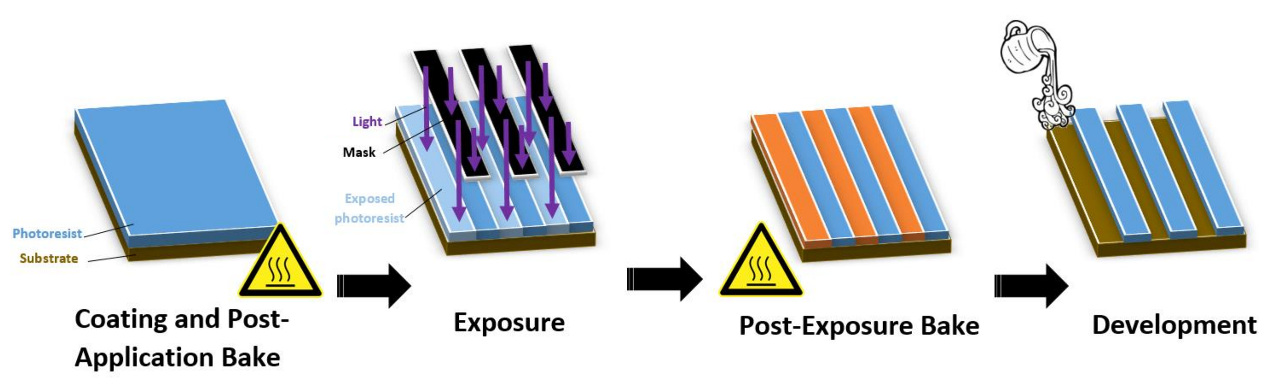
For all advanced microelectronic chips produced nowadays, the patterning of the electronic circuit on silicon is realized through various steps of photolithography, a process during which light is used to print a pattern on a substrate.
In the past decades, the miniaturization trend predicted by Moore's law has required photolithography to use light with continuously shorter wavelength in order to print smaller critical dimensions.
Currently, 193nm laser light is used for high volume manufacturing of advanced electronic devices.
The main candidate for mass production at the next technology node is Extreme UV technology, using light at 13.5nm wavelength, in order to achieve sub-20nm pattern printing.



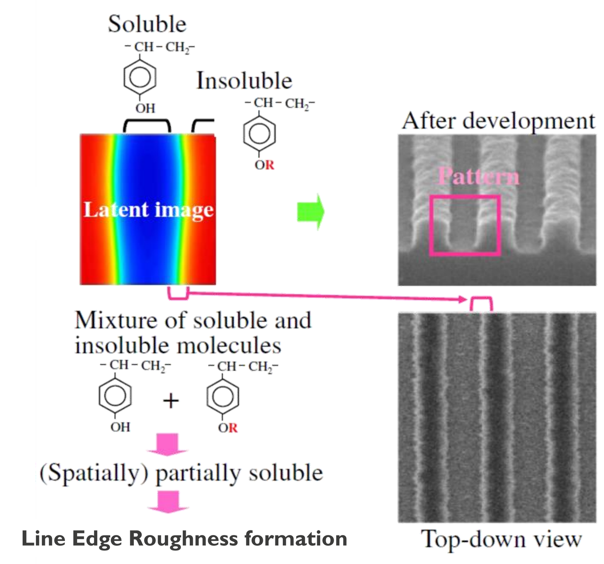
Active research in EUV lithography tries to simultaneously improve the best resolution that can be printed in a single exposure, increase the sensitivity of the process (shorten the time of light exposure) and decrease the roughness of the pattern printed.



Development of photoresist

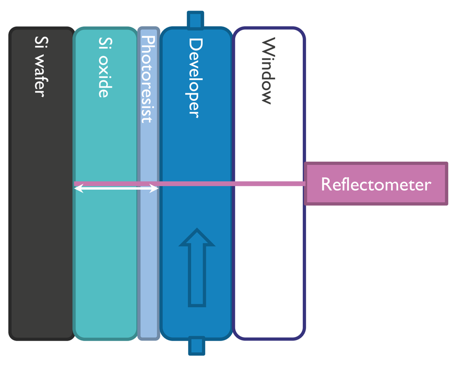


In the process of photolithography, a photoreactive polymer, called photoresist, is spin coated on a wafer, solvent is removed by a bake step, then the wafer is exposed to light through a patterned mask. This activates photo-acid generator (PAG) molecules, that then catalyse a cleavage reaction during a post exposure bake (PEB) step. This cleavage of functional groups leads to a change of the hydrophilicity of the polymer, and thus of their solubility in solvent.
When an appropriate solvent is poured onto the wafer during the development step, selective dissolution of the polymer film is achieved between exposed and unexposed region.
If the exposed region is removed, we talk about positive tone development (PTD);
if the unexposed region is dissolved, it's a negative tone development (NTD).

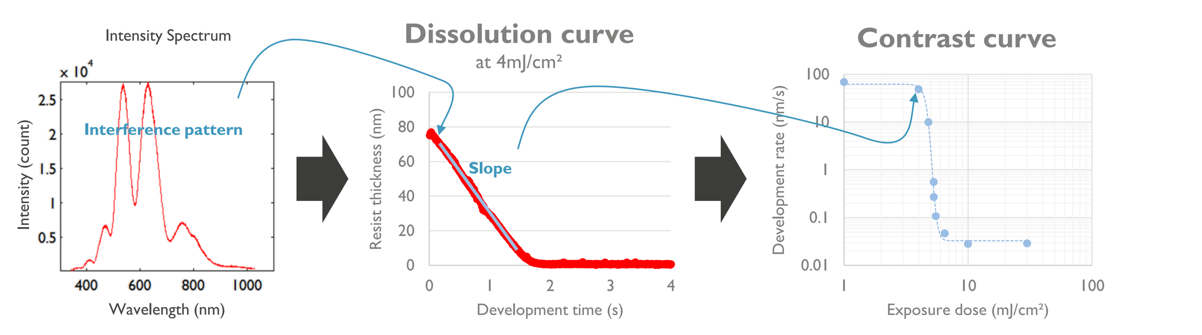


Dissolution Rate Monitor tool

The DRM tool, developed at imec in collaboration with TEL, permits to continuously measure the thickness of the film when the photoresist is put in contact with a constant flow of developer solution.



Development rate can then be measured at various exposure dose.



Reflectometer records interference pattern every 10ms

Peaks of interference are translated into film thickness through time

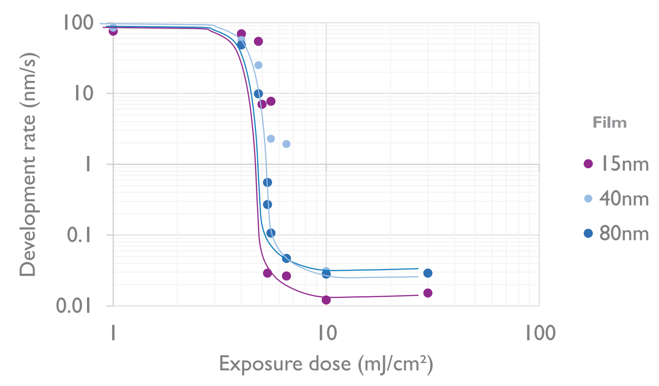
A fitted linear slope determines the development rate (DR) for each exposure dose

The minimum DR (Rmin), the maximum DR (Rmax) and the steepness of the contrast are the parameters that describe the resist development in lithographic modelling software

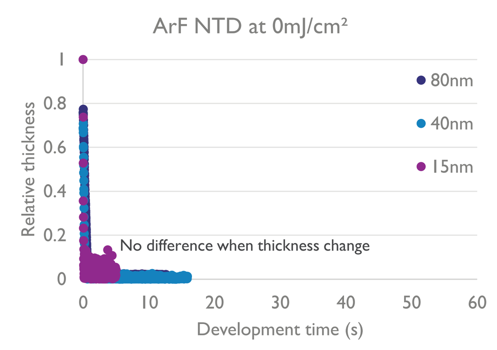
NTD

Impact of photoresist thickness

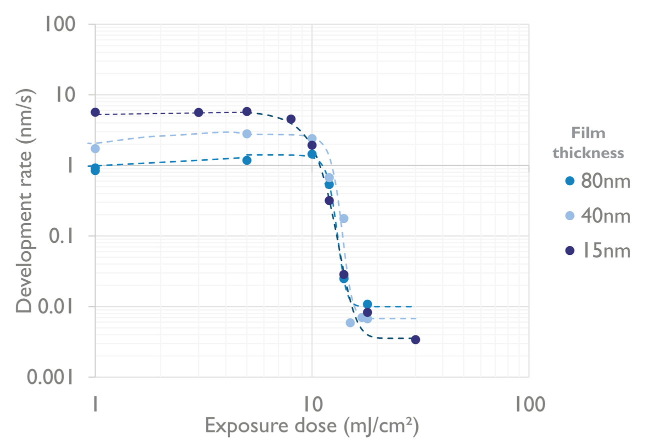
193nm resist platform



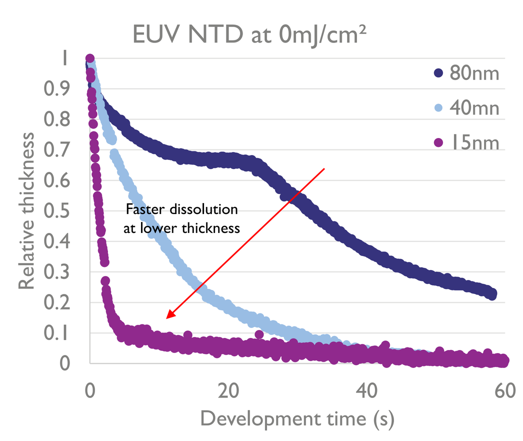
For 193nm exposure, resist films with different thickness show similar contrast curve and dissolution curve.



EUV resist platform

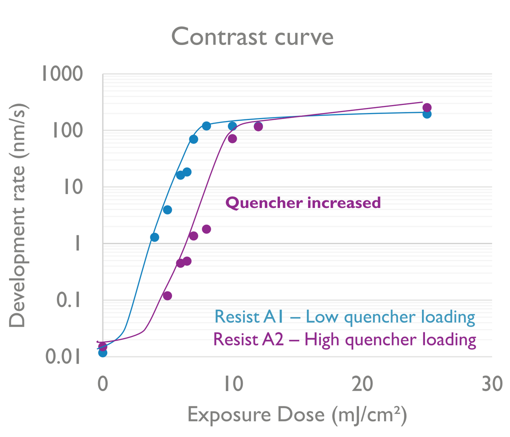


For EUV photoresist, non linear behaviour is observed at low exposure dose for thicker resist film: the development rate slows down with resist depth. Thus, the initial (first 15nm) dissolution rate of the thick film is higher than its mean DR.
As a consequence, thinner resist film shows a better contrast.

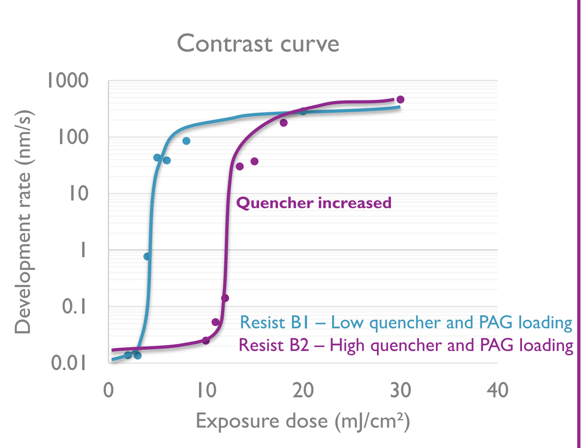


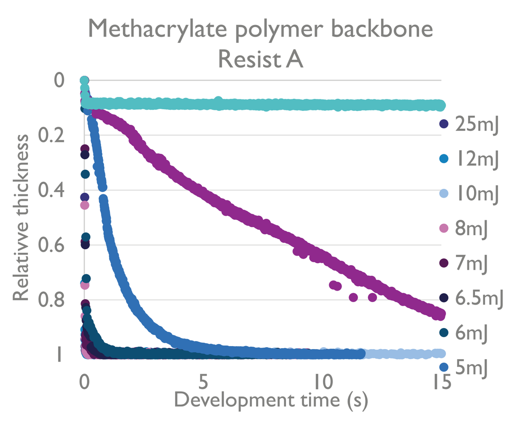
PTD

Impact of the photoresist formulation

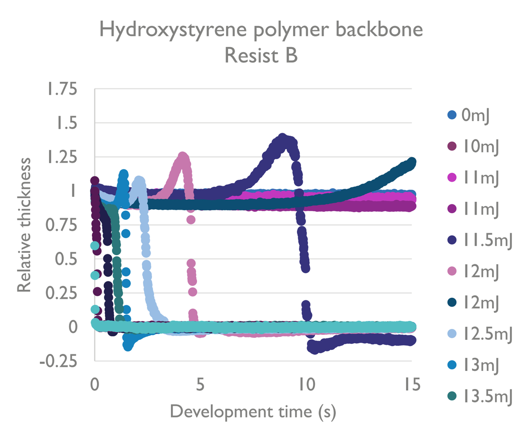


An amine base, named quencher, can be added to the photoresist formulation to reduce the diffusion length of the photo-acid catalyst during PEB.
We observed that adding this quencher pushes the solubility switch towards higher dose, and that the minimum and maximum development rate are increased by 30% due to the plasticizing effect of these additive molecules



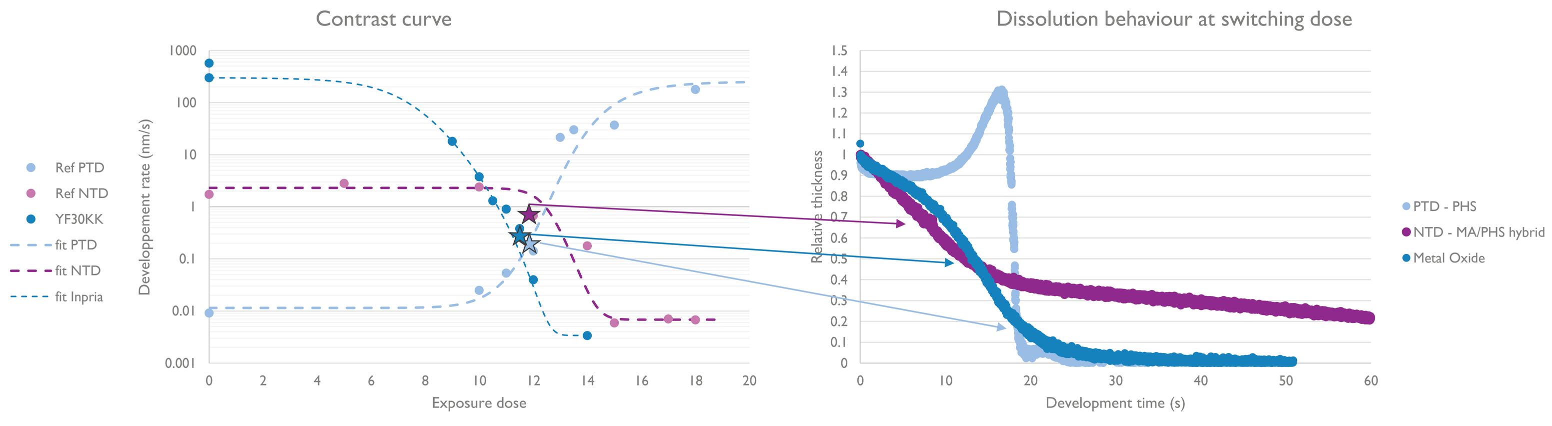


Advanced EUV resist are based on a poly-hydroxystyrene backbone, which differs from the methacrylate-based resist inherited from 193nm resist technology.
We observed that the more advanced EUV resist shows a strong non linear behaviour during dissolution of partially exposed polymer:
After a delay time in contact with the developer, the resist start to swell, and once the polymer chains are sufficiently solvated, a fast dissolution happens.



Comparison of photoresist platforms

We compared the contrast curve and dissolution behaviour of advanced EUV photoresist.
PTD resists use a TMAH water solution as developer and NTD resist use a solvent based developer.
For traditional chemically amplified resist (CAR), it is known that the dissolution of hydrophobic polymer by solvent is slower than the dissolution of hydrophilic polymer by water, notably due to the solvent penetration (size of the molecule).
A novel type of photoresist has recently appeared and made their proof, it is the metal-oxide resist, based on inorganic thin film condensation. These resists are NTD, but they show a very strong contrast, equivalent to PTD-CAR.



But we have seen that just comparing contrast curves is an uncomplete analysis of the dissolution properties of a resist, because different resist platforms show very different dissolution curves at switching dose. We believe that a better understanding of these different behaviours should help the resist design and lead to resists with better performances.

Conclusion

We have proven that the DRM tool developed at imec is able to monitor the dissolution behaviour of EUV photoresist, and to capture the specificity of different resist formulations and platforms. With the data collected, we will be able to start a collaborative work with resist suppliers, for example by understanding how to tune the polymer chemistry in order to achieve desired dissolution curves. This additional insight should help to develop new photoresists with better lithographic performances.

Sources of the drawings and figures that are not produced by the authors or Imec :
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