Softbake of Photoresist Films

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Softbake: Purpose

After coating, the resist film contains a remaining solvent concentration depending on the resist, the solvent, the resist film thickness and the resist coating technique.

The softbake reduces the remaining solvent content in order to:

è avoid mask contamination and/or sticking to the mask,
è prevent popping or foaming of the resist by N_2 created during exposure,
è improve resist adhesion to the substrate,
è minimize dark erosion during development,
è prevent dissolving one resist layer by a following multiple coating, and
è prevent bubbling during subsequent thermal processes (coating, dry etching).

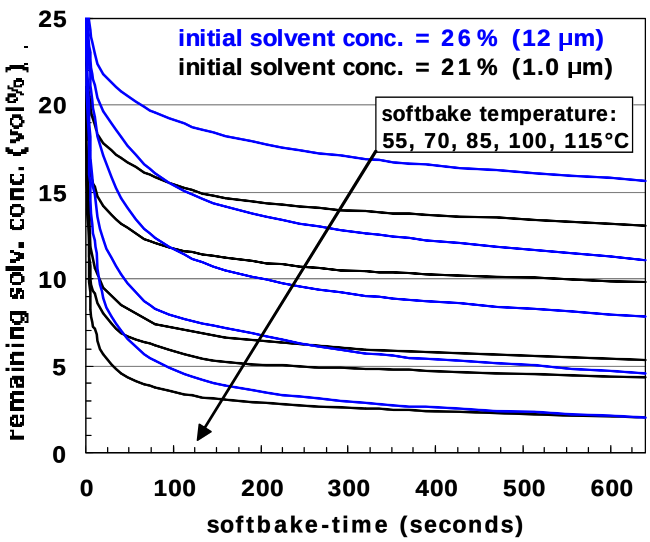
Softbake and Remaining Solvent Concentration

After spin coating, the typical average PGMEA concentration in the resist film is between 20% (thin films) and 40% (thick films). Softbaking reduces the remaining solvent concentration in the resist by solvent diffusion (thermally activated with the activation energy E_a) in the resist bulk with the diffusion constant D as a function of the temperature T and solvent concentration C, and evaporation (rate Φ thermally activated with the activation energy E_a*), as a function of the temperature T and the resist surface solvent concentration D_o:

$$D(C,T) = A \cdot \exp\left[-E_a / kT\right] \cdot \exp\left[\frac{C}{\alpha + \beta C}\right], \qquad \phi \propto D_O \cdot \exp\left[-E_a^* / kT\right],$$

Hereby, the solvent evaporation rate drops during softbake time for two reasons: i) The evaporation rate is proportional to the surface solvent concentration, and ii) the solvent diffusion towards the resist surface strongly drops in solvent-poor resist.

The figure right-hand plots the evolution of the average solvent concentration for two film thicknesses during softbake at various temperatures. Especially in thick resist films, the formation of a strong solvent concentration gradient (not shown here) can be observed.



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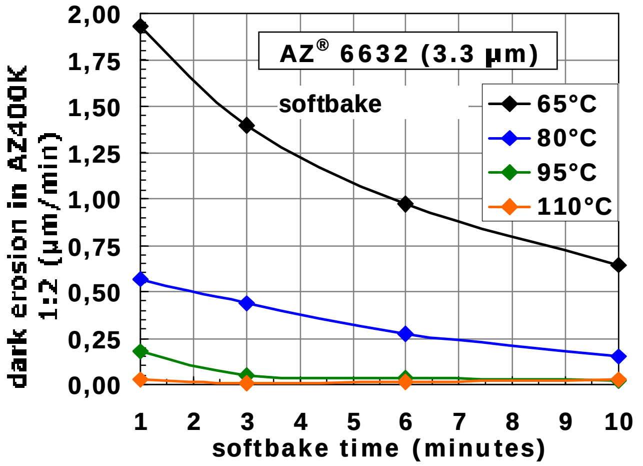
Remaining Solvent and Dark Erosion

Insufficiently softbaked resist films reveal a high dark erosion during development, with the remaining resist structures too small and less sharp than desired. The figure right-hand shows the dark erosion of a 3.3 µm thick AZ® 6632 film softbaked at various temperatures and times.

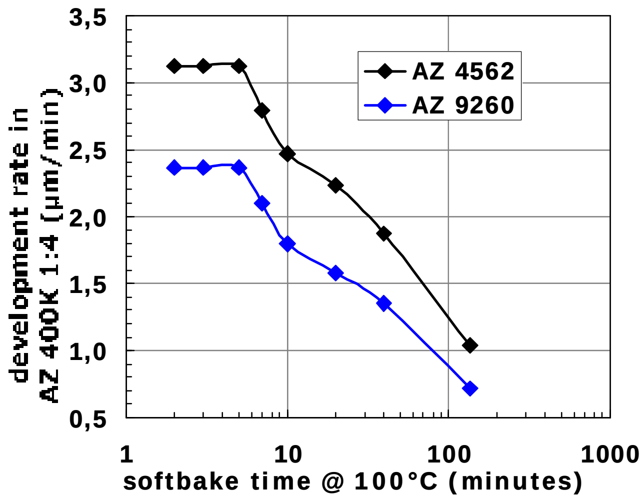
In order to demonstrate the impact of softbake parameters on dark erosion, an unusual strong developer concentration (AZ® 400K : H_2O = 1:2) has been applied.



Softbake Parameters and Development Rate

Beside solvent reduction, a long/hot softbake thermally decomposes a part of the photo active compound (here: DNQ) thus reducing the development rate (fig. right-hand).

Therefore, despite a lower dark erosion, the longer necessary development rate may increase the total dark erosion. As a rule of thumb, a compromise between sufficient solvent evaporation, and minimized DNQ-loss is a softbake at 100°C for 1 minute per µm resist film thickness on a hotplate.



Oven or Hotplate?

Compared to a hotplate, the much more distinct temperature hysteresis of an oven as well as the different heat transfer mechanism (convection in stead of heat conduction) causes – especially for short (few minutes) – baking steps (softbake, reversal bake, hardbake) or substrates with high heat capacity (thick glasses and ceramics) different effective temperatures in the photoresist and time intervals for the required final temperature. Without direct contact to plane metal surfaces, substrates need at least 10 minutes in an oven to approach temperatures of approx. 5°C below the desired temperature. Temperature differences of 5-15°C between various locations in an oven and the temperature displayed are unfortunately typical, and hardly allow temperature critical processes.

If using a contact hotplate (without gap between hotplate and substrate), the impact of the thickness and heat conductivity of different substrates (Si, glass, ceramics) on the attained temperature of even thick resist films is minor, while a gap (desired or undesired due to e. g. strained and curved substrates) between substrate and hotplate may change the temperature profile.

Softbaking of Thick and Very Thick Resist Films

The thicker the resist film, the smaller the possible softbake parameter window formed by baking temperature and time:

A softbake much too cool/short may cause bubbling and foaming of the resist film due to the nitrogen generated during exposure. Additionally, the remaining solvent concentration causes a high dark erosion.

A softbake too cool/short may cause bubbles in the resist close to the substrate by N_2

formed during exposure. These bubbles are sometimes not visible before 'free-developed'. Additionally, the dark erosion is increased.

A softbake too hot / long decomposes a fraction of the photo active compound thus decreasing the development rate. Additionally, the very low solvent concentration embrittles the resist film making it susceptible to the formation of crackles.

'Bubbles' in the resist film - despite a sufficient softbake - are in many cases cracks causes by mechanical stress due to the N_2 generated during exposure. If the N_2 cannot dissipate from the resist film fast enough due to the high resist film thickness, strong mechanical stress occurs expanding and cracking the resist.

As a rule of thumb, a compromise between sufficient solvent evaporation, and minimized DNQ-loss is a softbake at 100°C for 1 minute per µm resist film thickness on a hotplate.