A novel approach for the reduction and inspection of sidewall roughness of patterned resist

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In micro- and nanoelectronics, surface roughness, sidewall roughness and line-edge roughness (LER) of patterned resist profile is always an important issue. With the shrink of line-width down to 10 nm, LER has become a crucial bottleneck for the technical development. In our earlier work[1], surface roughness had been successfully addressed by thermal radiation induced local reflow (TRILR) on the very skin region of the resist. The principle of the TRILR process is shown in Figure 1(a). Under thermal radiation, a temperature gradient from the surface to the inside is established. The surface skin about 10-15 nm deep is first heated up to the glass transition temperature (T_g) so that PMMA in that region undergoes a phase change into liquid state, leading to a local reflow. By this method, surface roughness is efficiently reduced but the whole profile is negligibly changed. In this work, we report our recent work to extend the TRILR process to the sidewall of patterned resist for the reduction of line edge roughness.

Using high resolution electron beam lithography by JEOL6300 beamwriter, lined mesh pattern of PMMA with the width of 22 nm and height of 500 nm was first replicated as shown in figure 1(b). The mesh pitch is 500 nm and the aspect ratio (height/width) is over 20. To heat the sidewall of the resist lines, the mesh pattern was tilted to ensure the sidewall is faced to the heat radiation. By the same arrangement, the sidewall roughness was optically characterized by reflection spectra, in which the interference peaks carry the roughness information from the sidewall of the lines. Figure 3 schematically illustrates the light route going through the resist lines. When the sample is tilted from 0° to 5°, a red shift in the interference peaks is observed. Further increasing the tilt angle to 15 °, a blue shift is observed. The shifts of the interference peaks can be explained by the interference law: $\delta = (2k+1)\frac{\lambda}{2}$. To enhance the light reflection from the sample in spectral measurement, a metallic film is coated on one side of the lines, as schematically illustrated in figure 4.

By summary, we have developed an effective method to reduce sidewall roughness based on thermal radiation induced local reflow without de-shaping the whole profile. Optical reflection spectra is also used to inspect the sidewall roughness of patterned resist. Our understanding is that there is a strong correlation between sidewall roughness and line-edge roughness (LER). Therefore, we believe our work provides this community with an encouraging opportunity for the reduction of LER to meet the requirement of line width shrink in the modern development of IC circuit technology.

[1] MNE 2015 oral: An effective approach for reducing surface roughness of PMMA in grayscale EBL by thermal radiation induced local reflow.

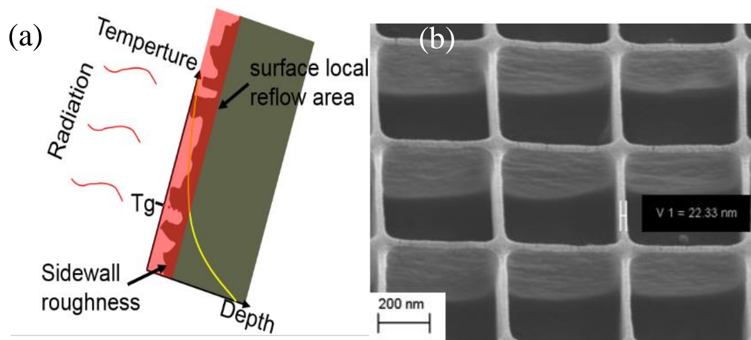

Figure 1. (a) The principle of TRILR process: In the top part heated region a local reflow occurs, removing the roughness. (b) The SEM image of the mesh in PMMA with line-width of 22 nm.

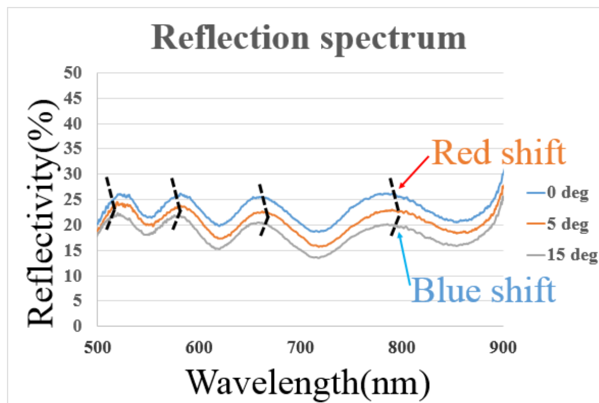

Figure 2. Optical reflection spectra from the PMMA mesh. The interference peak width reflects the roughness scale qualitatively.

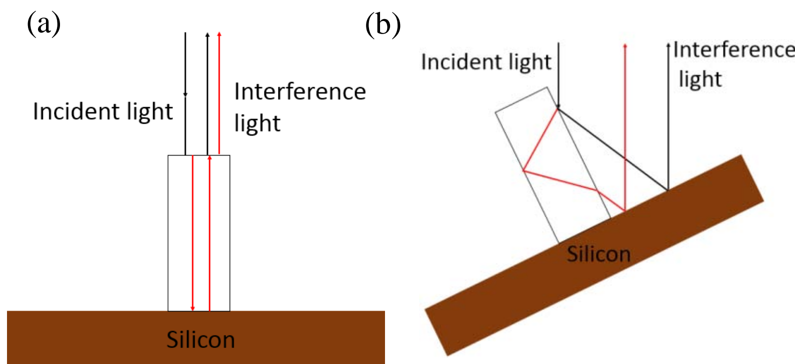

Figure 3. The light routes explains the origin of the red shift (a) or blue shift (b) in the interference peaks.

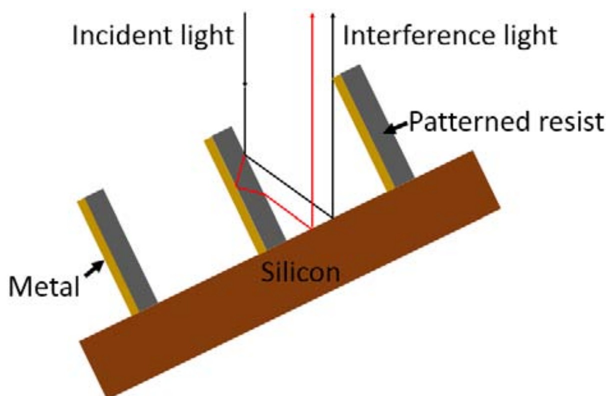

Figure 4. The scheme to inspect the sidewall roughness: A layer of mental deposited on the other side of the patterned resist is to enhance the reflectivity of the incident light.