Thermal control extends heated stencil's life-time

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Stencil lithography is a shadow mask technique for parallel surface patterning with sub-μm resolution for a wide range of applications [1, 2]. However, the clogging of stencil apertures and the gap between stencil and substrate remain two main technical challenges. The first limits the stencil's nano-apertures' life-time in one pump-down and the second affects the patterning resolution. Individual methods have been proposed to reduce the clogging [3] or to decrease the gap [4]. We already demonstrated a solution where both the aperture clogging is prevented by heating the membrane with an integrated micro-hotplate [5, 6] and the the gap is reduced by thermal actuation of the membrane. Despite these advantages, the effectiveness of heating the stencil is reduced for metal patterning, as the evaporated metal layer increases the thermal conductance of the SiN membrane to the bulk Si frame. In this work we increase the stencils' life-time 10 times by confining the metal deposition area on the membranes using a secondary shadow mask.

Fig. 1 shows the standard fabrication process and the optical image of the heated membrane. By heating the membrane up to 700 ^{o}C during evaporation, the material condensation on the membrane is reduced and the aperture clogging is prevented (Fig. 2a). By comparison, the non-heated aperture is almost completely clogged after 200 nm Al deposition (Fig. 2b). Due to the thermal actuation of the membrane during heating, the inherent stencil-substrate gap is reduced by up to 25 μm. This closer proximity increases the pattern resolution by 150%.

These figures of merit quickly degrade with the accumulation of metal on the periphery of the heated membrane. In order to maintain a constant membrane temperature, the input power has to compensate for the decrease in thermal resistance to the bulk Si. For 200 nm of evaporated metal the power necessary to maintain a temperature effective for unclogging is large enough to break the membrane. Therefore, the metal thickness determines now the life-time of the heated membrane. In this work an extra aligned shadow mask localizes the metal deposition on the heated membrane (Fig. 3). At constant input power, the temperature in the membrane center after a localized deposition of 100 nm Al drops by 20 ^{o}C, whereas without thermal confinement it decreases by 200 ^{o}C, as shown in Fig. 4. Thus, the heated stencil can be used in-situ 10 times longer.

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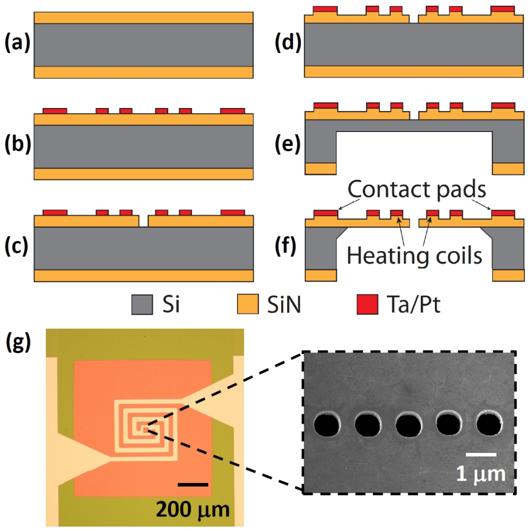

Figure 1: (a-f) Schematic process flow. (g) Optical micrograph of the heated membrane and zoom-in SEM image of the stencil apertures.

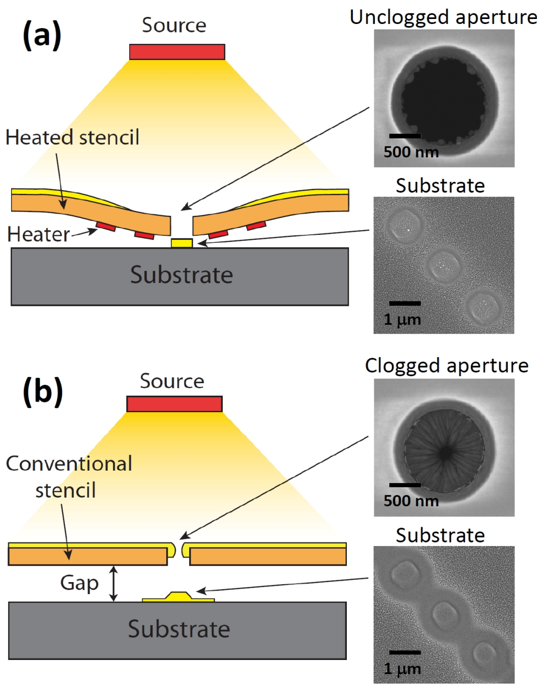

Figure 2: (a) Stencil lithography with heated membrane, which greatly improves the resolution by unclogging the aperture and minimizing the gap; (b) Conventional stencil lithography. The pattern on the substrate is distorted, due to the clogging of the stencil aperture and the gap. 200 nm of Al was deposited in both experiments for comparison.

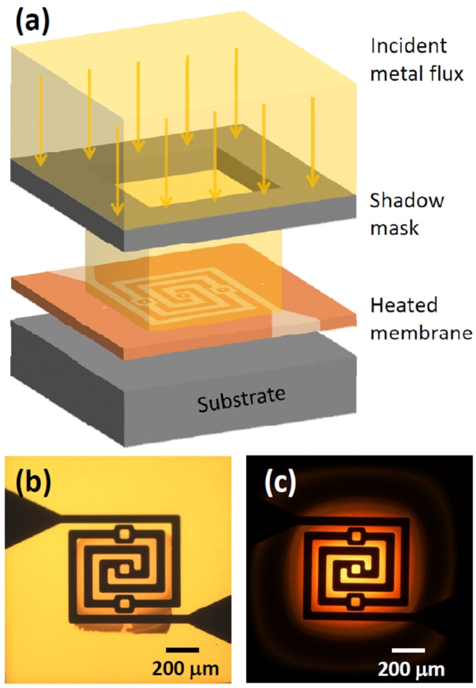

Figure 3: (a) Localized deposition on heated membrane; Optical images with backside illumination of 100 nm Al deposited on the heated membrane (b) with thermal confinement and (c) without thermal confinement. The thick Al layer on the less heated area of the membrane increases thermal dissipation, which decreases the average temperature.

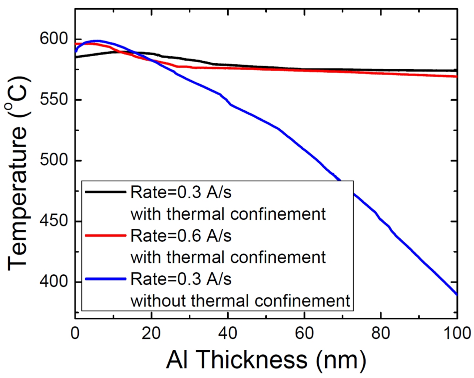

Figure 4: Graph showing the average temperature of the heated membrane vs. the thickness of evaporated Al. The localized deposition extends the life-time of the heated stencil. The temperature with localized deposition of 100 nm Al drops by 20 ^{o}C, whereas it decreases by 200 ^{o}C in the case of deposition without shadow mask.