One-step air bridge fabrication technique using 3D e-beam lithography

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A new technique is demonstrated for the realisation of air bridges using one lithographic step. Gray scale lithography is used for the formation of 3D profiles on polymethyl methacrylate (PMMA) where a variable dose exposure is applied to create a trapezoid profile for the air bridge. In previous 3D electron beam lithography (EBL) methods the span area was exposed to a low dose or a low acceleration voltage [1,2,3]. Thus, the required discontinuity with the surrounding area for the lift-off process was created. In this technique, no exposure of the span area is needed. Another exposure of a gradient dose is applied to the sides of the highest part of the air bridge. The created profile, after developing the resist, is depicted in Figure 1. The surfaces with red and blue colour represent the metal to form the air bridge and the metal to lift-off, respectively. Using this configuration, the deposited metal at the sides of the top part of the air bridge is connected to the surrounding metal to lift-off and disconnect from the air bridge. The electron dose used in this area has to be smaller than the minimum dose that penetrates the total resist layer, so that the deposited metal does not reach the substrate. This method takes maximum advantage of the resist thickness for the fabrication of high structures, as no part of the resist is sacrificed.

The implementation of a one-step 3D EBL technique requires a method for the creation of both smooth slopes and sharp edges on the resist. The continuity of the metal layer on the air bridge body ensures that the structure will not collapse. At the same time, high contrast profiles are needed for the lift-off process. A very interesting technique has demonstrated the creation of sloped, stepped and vertical profiles on the same substrate [4]. After applying a two-step exposure and development procedure, a post thermal reflow generates smooth slopes on the highly exposed areas while the stepped profiles remain at the areas exposed to low doses. However, for the purposes of this work, a one-step procedure was found to provide sufficient results without need of post-thermal treatment. Smooth profiles can be generated from a stepped-pattern if the steps are designed at the optimum width. The accumulation process of adjacent electron doses, considering the proximity effect, has previously been presented [5] demonstrating the fabrication of continuous sloped profiles using 3D EBL.

For this experiment, four layers of 12 % PMMA were spun to compose a 5 μm thick layer of resist which can be penetrated using an electron beam accelerated by 100 kV voltage. Several geometry and dose tests were executed for the optimisation of the pattern design. The width of the single-dose steps was varied from 50 nm to 1 μm. The slopes of the designs with steps narrower than 100 nm proved to be very steep while the gradient was small for steps wider than 500 nm. The optimum step width proved to be equal to 200 nm, providing relatively smooth profiles with slopes close to 45^{o}. Dose tests were taken for the designs with 200 nm wide steps, indicating that electron doses higher than 520 μC/cm^2 are enough for the penetration of a 5 μm thick layer of PMMA.

A group of structures with 20 μm width and various lengths is depicted in Figure 3. The height of the structures is approximately 5 μm as expected and the maximum length is 30 μm. Designs with 20 μm length and width between 10-20 μm proved the most reliable in terms of process yield. One of the main advantages of the current technique, where the patterns are defined using EBL, is the high accuracy of the air bridge placement. The maximum error of the point that the air bridge contacts the substrate was found to be ±200 nm. Therefore, this method can be ideal for the implementation of interconnections for inductors, multi-finger transistors and for the suppression of the parasitic modes of propagation in CPWs [6].

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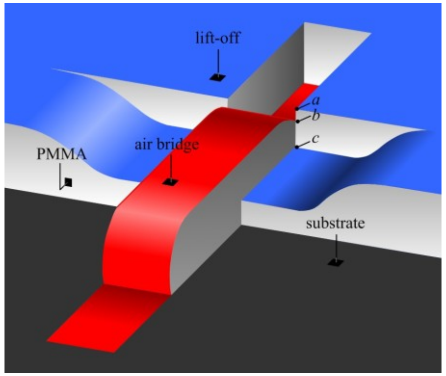

Figure 1. The desirable 3D profile on the PMMA after development. Levels *a*, *b* and *c* at the critical corner indicate the level of the metal to be lifted-off, the level of the air bridge and the intermediate level on the side of the structure, respectively

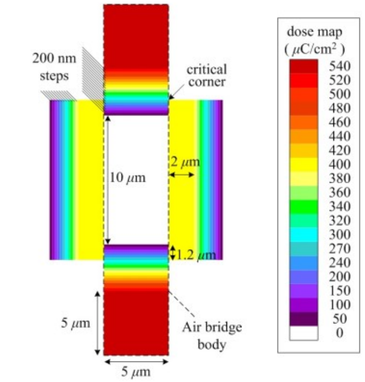

Figure 2. Design example of air bridge. The doses corresponding to the colours of the design are illustrated at the dose map.

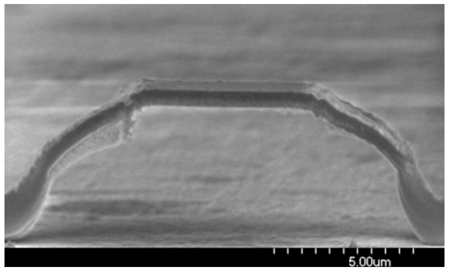

Figure 3. Stretch to 50% in *MS Paint* reduces the size of your image by a factor 4 (e.g. 1MB becomes 250KB upon saving your image). Use .

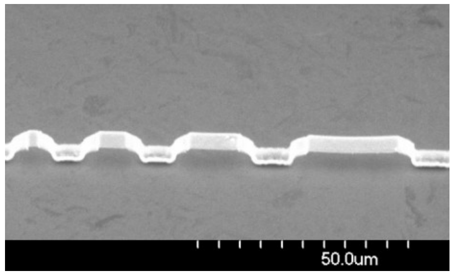

Figure 3. Fabricated 20 μm wide air bridges with.