# Patterned Cracks in the Buried Oxide Layer Improve Yield in Device Release from SOI Wafers

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The buried oxide (BOX) layer of silicon-on-insulator (SOI) wafers commonly serves as an etch stop and sacrificial layer in microfabrication [1]. However, when device release requires removal of the underlying silicon handle wafer, compressive stress in the BOX membrane can cause it to buckle and crack when freed [2]. These cracks can threaten the survival of delicate structures on top of the BOX. Thermally-grown silicon oxides, such as the BOX, are typically under considerable compressive stress at room temperature (300-500 MPa) from mismatch between the thermal expansion coefficients of silicon and silicon dioxide and the considerable temperature drop after oxidation [3, 4].

This paper shows that intentionally patterning cracks into the BOX substantially improves yield in the release of ultrasoft silicon cantilevers. We designed the crack patterns to direct crack formation to non-critical areas of the oxide membrane, and to reduce spontaneous cracking by allowing in-plane expansion of the membrane much like expansion joints in a bridge. Prior work has explored the initiation and patterning of cracks in tensile films, primarily using stiffeners [5-7]. This work attempts to direct cracking in compressive layers by lithographically patterning cracks into the film.

Patterned cracks were tested in the fabrication of ultrasoft, mass-loaded cantilevers for magnetic resonance force microscopy (Figure 1) [8, 9]. These cantilevers have a shaft thickness of 100 nm, a mass-loaded region at the tip 1 µm-thick, lengths of 85-200 µm, and estimated stiffnesses of 60-150 µN/m. Figure 2 shows the crack patterns tested on a typical die: (i) a "moat" encircling the three cantilevers on each die and (ii) a larger "Y" pattern. The fabrication process (Figure 3) was derived from previous work [8]. Prior to release, crack patterns were etched 80-100 % through the 1 µm-thick BOX, as shallower cracks were ineffective in preliminary runs. Photoresist was used to protect the frontside during the deep reactive ion etch (DRIE) through the handle wafer. A plasma asher subsequently stripped the photoresist. The wafers were gently cleaned in a hot bath of sulfuric acid and hydrogen peroxide and rinsed in still water baths; care was taken to minimize fluid forces on the released delicate membranes. Finally the cantilevers were fully released using hydrofluoric acid vapor to etch the BOX and frontside oxide. During release processing, wafers were visually inspected after every critical step and cantilevers were assessed for yield.

Figure 4 shows optical microscope images of the freed BOX membrane and cantilevers during release processing. Without patterned cracks, spontaneous membrane cracks frequently ran beneath the cantilevers and fractured them. The outer cantilevers were particularly stricken by cracks that formed near the corners of the die, which acted as stress concentrators. The patterned cracks successfully terminated many spontaneous cracks and prevented them from propagating towards the cantilevers. However, the Y pattern was too large, and spontaneous cracks often formed inside the pattern. The moat pattern was far more effective in protecting the cantilevers. Table 1 lists the final cantilever survival data and percentage yield by crack pattern. Cantilever yield for no patterned crack and for the Y-pattern was 35 %, while yield with the moat pattern was 68 %.

In conclusion, cracks patterned directly into the BOX were found enhance the release of delicate microdevices. Cantilever yield improved by almost a factor of two with the use of certain crack patterns. This result is important for the fabrication and safe release of extremely compliant structures using SOI wafers.

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Figure 1: SEM of ultrasoft cantilever with mass-loaded tip and optical spot.

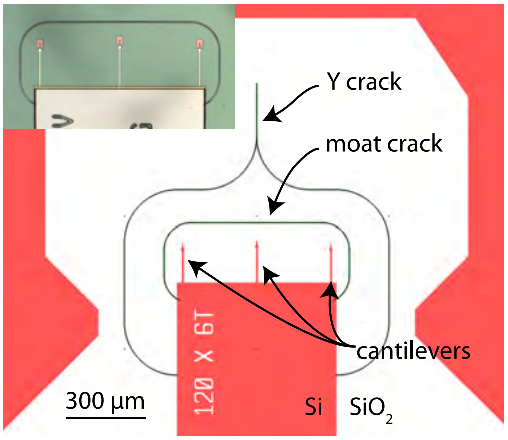


Figure 2: Y and moat crack patterns shown with topside silicon pattern in red. Each die has three cantilevers. Only one crack pattern per die was used. A smaller moat pattern (not shown) was used for shorter cantilevers. Inset: image of die tip with moat pattern pre-release.

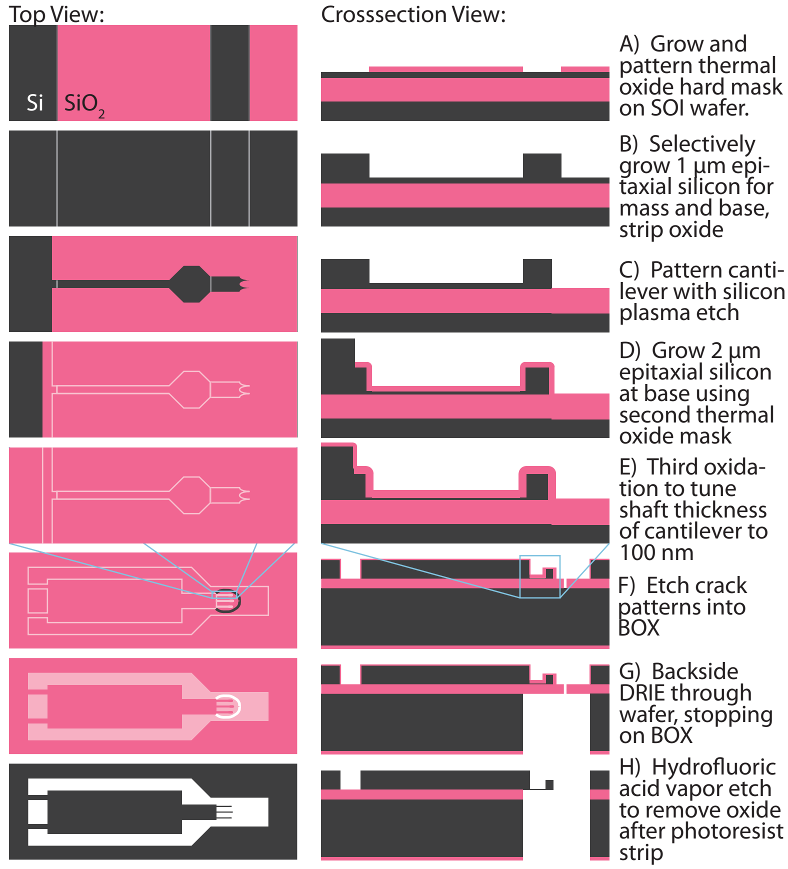


Figure 3: Fabrication process.

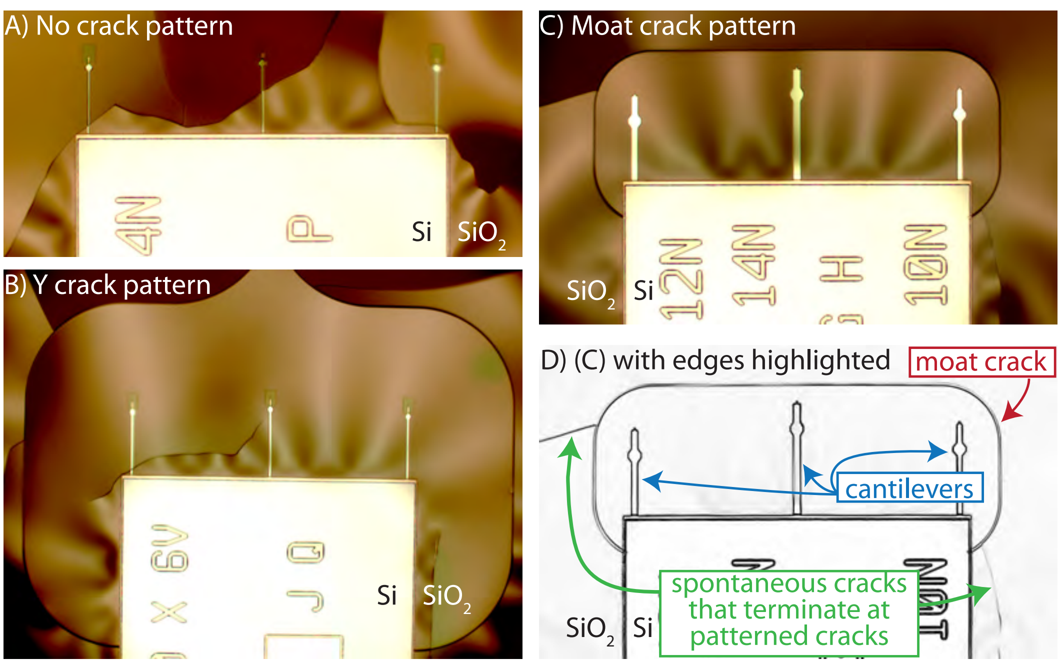


Figure 4: Optical microscope images of buckling and cracking in the BOX during release processing without (A) and with (B-C) pre-patterned cracks. In (A), all three cantilevers are fractured by spontaneous cracks in the BOX membrane. (B) and (C) both show spontaneous cracks terminating at patterned cracks. However, in (B), spontaneous cracking inside the large Y pattern has fractured the left cantilever. In (C), no spontaneous cracks are seen inside the moat pattern and all three cantilevers survive. For clarity, (D) shows (C) after edge-finding image processing with features labeled.

Table 1: Cantilever survival by crack pattern used. Percent yield in parentheses.

| Crack Pattern : | **No cracks** | **Y pattern** | **Moat pattern** |
|---|---|---|---|
| Cantilever Yield : | 148 of 420 (35 %) | 147 of 426 (35 %) | 573 of 846 (68 %) |