Numerical simulation of the kerf-less spalling technique in the presence of a non planar Aluminum- Silicon interface

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Outline

This study focuses on the feasibility to reuse of the parental Silicon substrate to obtain multiple layers in thermally induced spalling [1]. To this aim a numerical method for studying the system in presence of a non-planar Silicon-Aluminum (stressor layer) interface, caused by previous exfoliations inducing steps on the free surface of Silicon to reuse, is presented. The method is based on the Finite Element Method (FEM) and Linear Elastic Fracture Mechanics (LEFM) to compute the Stress Intensity Factor (SIFs) and predict the crack propagation of the initial crack depending on geometry and boundary condition.

Thermally controlled-induced spalling

- Exfoliation of thin crystalline Si layer by the difference between the thermal expansion coefficient (CTE) of Si and Al-stressor layer
- Initial sharp crack introduced by laser
- Controlled thermal load propagates crack through the Si substrate ⇒ detachment of ultra-thin Si layers.

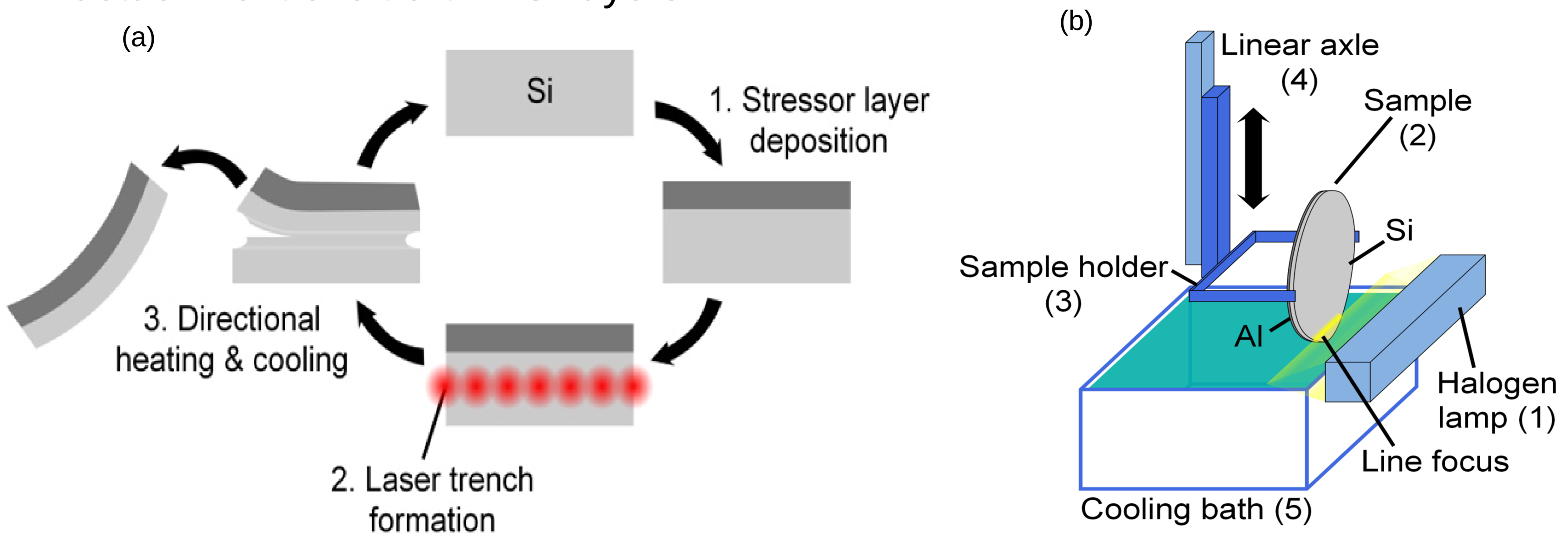

Fig. 1. (a) Process circle of exfoliation process: 1. Stressor layer deposition, 2. Laser trench formation, 3. Exfoliation by directional heating and cooling. (b) Sketch of experimental setup (not to scale): halogen-lamp (1), sample (2), sample holder (3), linear axle (4), cooling bath (5) [1].

Methodology and numerical approach

- SIFs: $\mathbf{K}(\sigma_0, h, \lambda \cdot h, \lambda_0 h, \Sigma)$ of the resulting bi-layered system [2]
- Planar thin layer ⇒ steady-state propagation
  $K_{II} = 0$ and $K_I > K_{IC}$ [3], where K_{IC} is the fracture toughness
- FE program FractureANalysis Code (**FRANC2D**) to compute SIFs and to predict crack propagation of the initial crack (J-integral algorithm and the minimum strain energy release rate criterion).

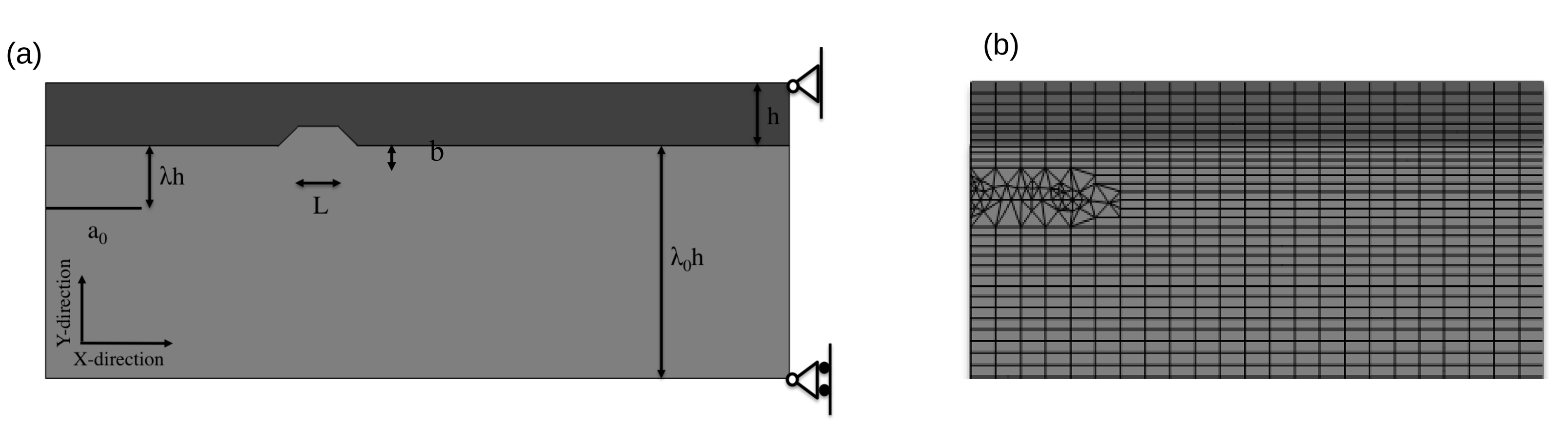

Fig. 2. (a) Geometry (not in scale) of the Si substrate with an Al layer evaporated on the top of it, in a 2D plane strain configuration and clamped in x=14 mm, where L is the length of the stepped region in the x-direction and b its height; (b) Zoom of the FE mesh, corresponding to λ=0.65.

Parametric study with uniform load

- Influence of the length of the stepped region, **L**, on the crack propagation and crack deflection, imposing a uniform **ΔT=-43° C** over the whole boundary, to achieve the steady state condition.

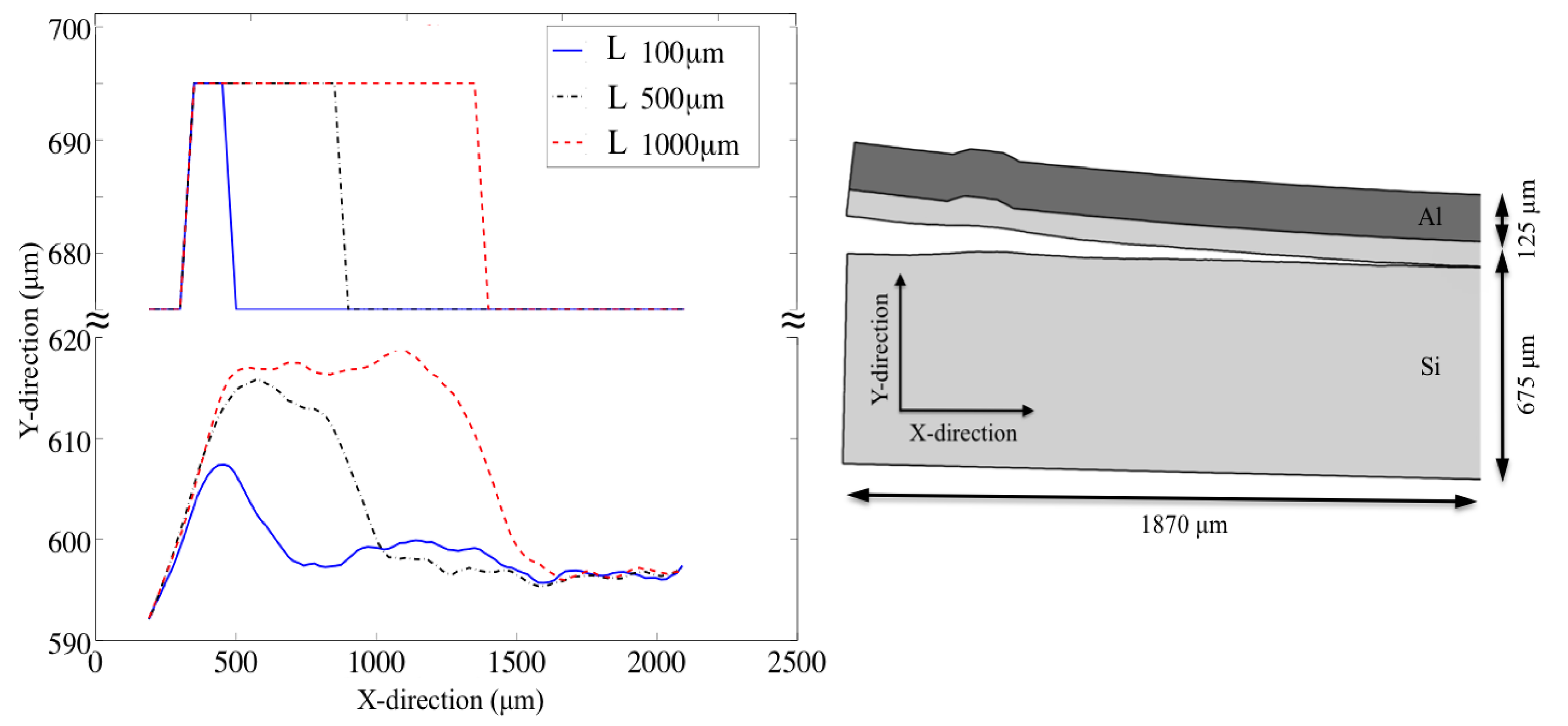

FIG. 3. Fig. 1 a) In the top: the geometry of the stepped Si-Al interface. In the bottom: simulated crack path providing the induced roughness on the Silicon substrate after reuse. b) Deformed mesh showing exfoliation for L=100 µm (zoomed region within the first 1870 µm along the x-coordinate).

Experimental test

- Inverted groove is obtained with dicing saw and and with etching in KOH to remove defects
- Aluminum deposition on the top of the Si-surface

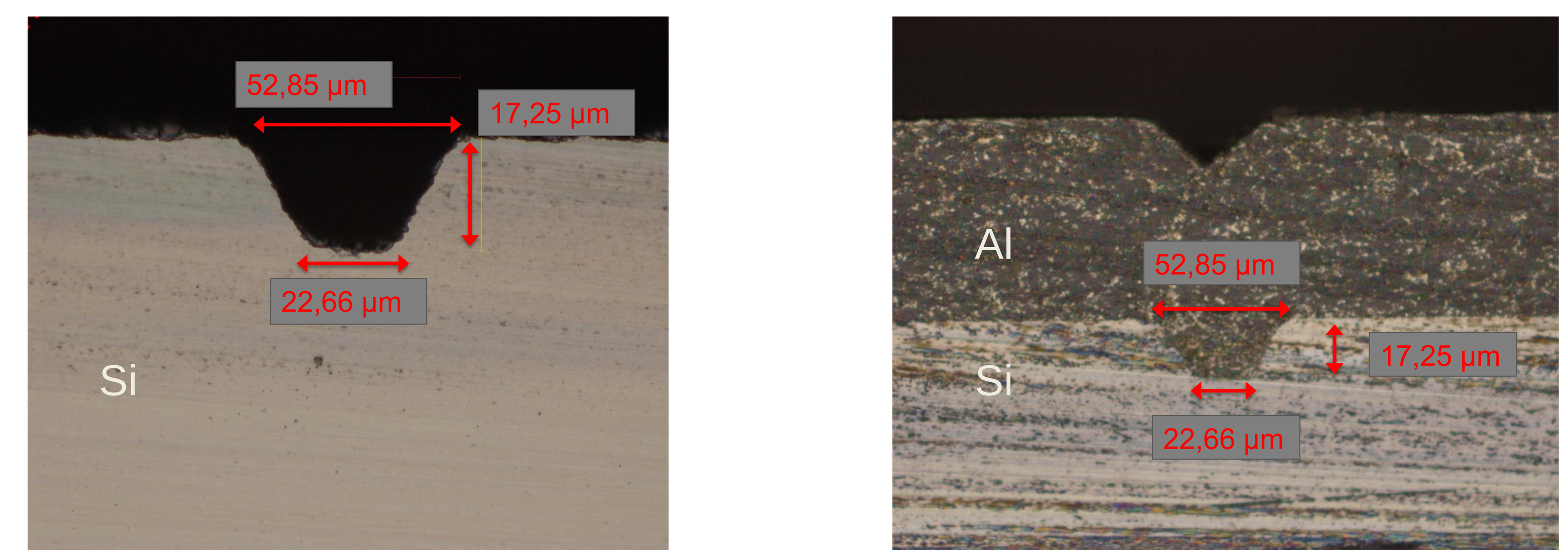

Fig. 5. (a) Silicon substrate with a groove performed before the deposition to reproduce the effect of a defect caused by second reuse. (b) Bi-layer after the Aluminum deposition

Experimental Results

- Two parental substrates after the exfoliation
- Profilometer measurements show a decrease in the height of the groove

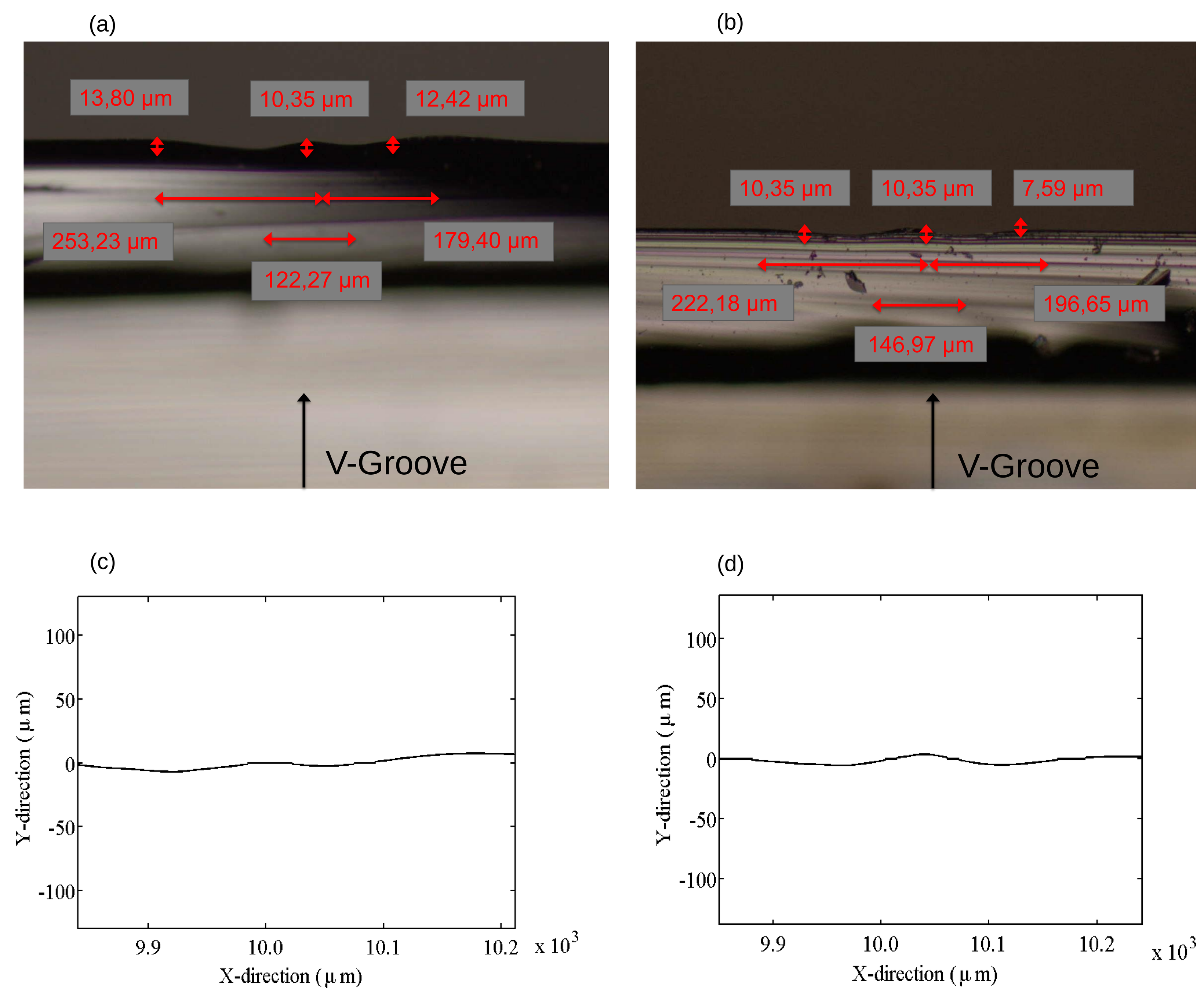

Fig. 6. (a) Silicon substrate after the exfoliation with initial b=17.25 µm and L=22.66 µm. (b) Silicon substrate after the exfoliation with initial b=15.04 µm and L=37.12 µm. (c) and (d) Profilometer measurements of the parental surfaces of first and second samples.

Conclusions

- Using a numerical method based on the FEM and LEFM we obtain a reduction of the height of the initial groove
- The experimental tests show a duplication of the groove and a decrease of its height.
- In the detached layer, the global variation of the groove is around 10 µm.

References:

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