

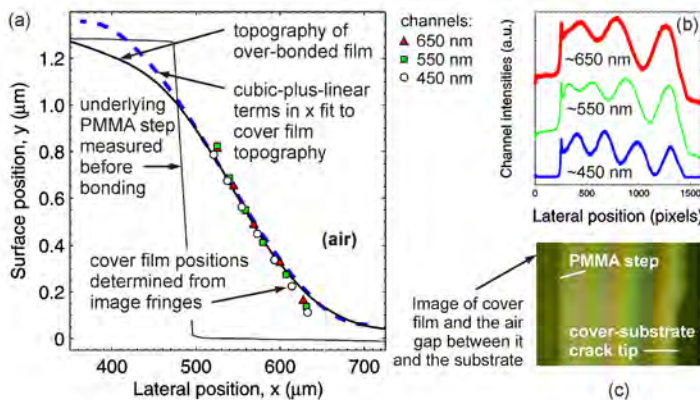
# Plasma-activated Inter-layer Bonding of Thermoplastics for Micro- and Nano-fluidic Manufacturing

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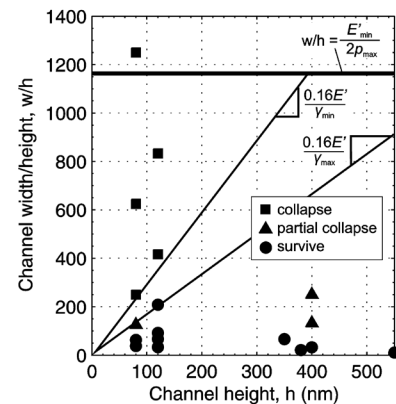
Plasma-activated polymer-polymer bonding is a promising way of encapsulating micro- and nano-fluidic channels across large substrate areas, without the substantial distortion of channel geometries that can plague thermally- and solvent-assisted bonding. The process involves treating the surfaces to be bonded with an oxygen or air plasma, and then pressing the surfaces together to allow an irreversible chemical bond to form [1]. A convenient method is desired for measuring the toughness of such a bonded interface. Simple crack-opening tests (whereby a blade prizes apart the two bonded layers and the length of the inter-layer crack determines the bond toughness [2]) are clumsy and hard to automate. We propose that built-in microscopic crack-opening test sites be distributed across manufactured substrates [3]. At each test site, a polymeric film bonded over a step in the substrate would peel back from the step after bonding, by a distance depending on the toughness of the bond. The presence of a wedge-shaped air gap between the covering film and the substrate leads to visible interference fringes, the spacing of which can be used to extract the bond strength (Figure 1). Arrays of these *in situ*

cracks might be imaged without removing the substrate from a production line and would allow us to monitor both substrate-to-substrate and cross-substrate bond toughness variation.

Bond toughness and polymer layers' surface energies are of particular relevance in planning the fabrication of very shallow fluidic channels whose widths,  $w$ , are much larger than their depths,  $h$ . The risk of channels' collapsing during fabrication must be controlled. For channels with  $h \sim 1 \mu\text{m}$  or less that are fabricated with thermoplastics, we expect collapsing to occur through local deformation of the surrounding material rather than through plate-like bending of the cover plate [4]. Our analysis suggests that the pressure applied during bonding, together with the polymer-polymer interface energies that exist before and after plasma-activated bonding, will delineate, on a  $w/h$  against  $h$  plot, regions in which collapsing will and will not occur. We have demonstrated nanochannels fabricated from polymethylmethacrylate (PMMA) that are 80 nm deep and 10  $\mu\text{m}$  wide and other channels that are 110 nm deep and 20  $\mu\text{m}$  wide (Figure 2).



▲ Figure 1: Results from a prototype bond toughness measurement feature. The topography of the film covering one side of a PMMA ridge (a) is determined with white-light interferometry (black line); a cubic-plus-linear function of the lateral position has been fit to the film topography, showing good agreement with an analytical small-deflections model of the cover plate. Symbols indicate the varying height of the air gap between substrate and cover film, obtained by interpreting a color interference image of the sample (c). The average red, green, and blue intensities present in the image are plotted (b) above the image.



▲ Figure 2: The PMMA nanochannel fabrication results. Our analysis suggests that provided  $w/h < E'/2p$  (where  $E'$  is the plate modulus and  $p$  is the pressure applied during bonding), channel collapsing is determined by the channel dimensions, the material's stiffness, and the surface energy change  $\gamma$  that occurs when a polymer-polymer interface is reversibly formed or broken. Possible lines separating regions of collapsed and intact channels are suggested; many more channel sizes need to be tested to map the  $w/h-h$  space confidently.

## REFERENCES

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