Cost Efficient Microfabrication Techniques enabled by Polycaprolactone

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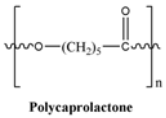
OBJECTIVE

Fabrication of microfluidic chips via an approach that is rapid and inexpensive, yet which promises a robust product, is critical if the reach of lab-on-a-chip technology is to be extended. Polycaprolactone (PCL) is a low melting temperature polyester that is easily spin-coated (to generate thin films) and readily trimmed by laser ablation (to generate fluidic networks). In the work described here, we have demonstrated methods of utilizing PCL as a bonding agent in thermoplastic microfluidic chips, and have also used it in fabrication of paper microfluidic devices in order to create low cost microchip prototypes. These chips have great potential as disposable point of care diagnostics devices.

MATERIALS AND METHODS

Part I Fabrication of PCL Microfluidic chips

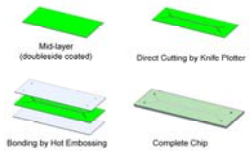
PCL was utilized as a bonding agent and sidewall material by spin-coating to a silicon wafer and transferring to a polymer sheet. Channels were produced by directly cutting the PCL-coated polymer using a blade in an xy-plotter; this step can be performed rapidly within seconds. Complete microfluidic channels were formed by enclosing the PCL channel within layers of various capping materials (e.g. acrylic, polycarbonate, polyester). The bonding was performed in a hot press (CARVER 3851-0, 100 psi, 150° F). This simple fabrication approach allows for easy incorporation of design modifications in the prototyping process.



T_m = 60 ° C
T_g = -60 ° C

Figure 1. PCL, dissolved in chloroform at concentration 0.03%, is spin coated on a silicon wafer. Once dried, the PCL film (green) can be transferred onto a polymer sheet in a hot press.

Figure 2. Channel designs are directly patterned on a thin polymer sheet that is coated with PCL film on both sides. A top and bottom layer are added to enclose the cut-out channel. The whole assembly is heated and pressed to complete the bonding process.



Part II Fabrication of Paper Microfluidic Devices using PCL

Direct Laser Writing

PCL was also utilized to create paper microfluidic devices using filter paper (hydrophilic) with a home-made PCL backing (hydrophobic). Channels were created by direct writing using laser ablation to define the hydrophobic boundaries. The cut areas became hydrophobic as the porous cellulosic network filled with molten PCL during ablation. Samples were readily introduced into the channel by capillary action. These fabrication approaches are rapid and simple, and result in inexpensive microfluidic platforms, which may be used as diagnostic devices in resource-poor settings.

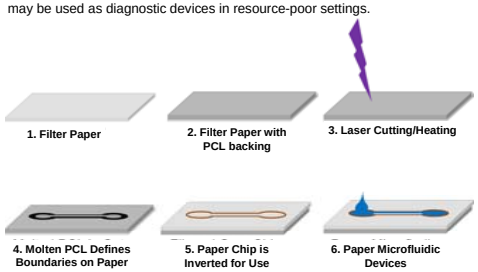


Figure 3. A sheet of filter paper was utilized as a substrate (1). PCL film was pressed onto the filter paper to create a double layer chip of hydrophobic and hydrophilic materials (2). The chip was laser-ablated on the PCL coated side (3). This produce a pattern on the PCL side (4) and when flipped over had a noticeable replication of the pattern due to the PCL melting into the paper (5). When water was placed on the paper side, the fluidics constrained by the hydrophobic boundaries created by the molten PCL (6).

RESULTS

Microchips with different designs can easily be fabricated using PCL as the bonding medium. A double-Y microchannel, shown in Figure 4 was fabricated via this approach, and then used for on-chip separation of cellulose nanocrystals.

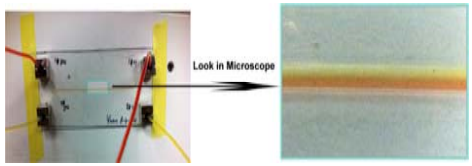


Figure 4. Double-Y channel for diffusion-based nanocrystal purification.

Multilayered microstructures can also be fabricated using PCL as the bonding material. Figure 5 shows multi layer chip (3 layers of microchannels) comprised of polycarbonate (PC) pieces bonded with polycaprolactone (PCL). Top and bottom layers were added (for a total of 5 layers) and bonded together with PCL film to form the complete microsystem with vias for external fluidic connections.

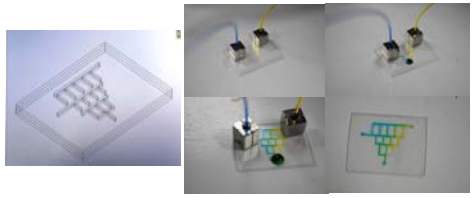


Figure 5. The schematic of the 5-layered microchannel system; trimetric view (left). Blue and yellow dyes are introduced at the two inlet and mixed in the channel to produce the green dye at the outlet.

PCL is biocompatible and has been widely used as a coating agent for tabletized pharmaceutical formulations. Its biocompatibility makes it suitable for various bioanalytical applications.

An advantage of PCL is that it can be modified to include functional groups, such as amines, which can be further utilized to attach molecules of choice for various applications. Amine groups were selected for derivatization of PCL since there exist a number of established chemistries for conjugation of biomolecules and other ligands via this functional group.
Ethylene diamine was mixed with PCL and solution cast. The primary amine groups were selectively detected with a solution of fluorescamine. As shown in Figure 6, an intense fluorescence signal is observed in the presence of primary amines (Group 2), while the control (Group 1) shows no fluorescence.

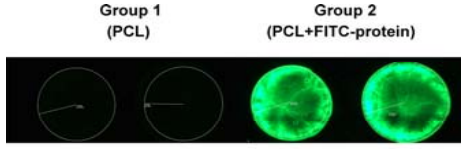


Figure 6. PCL Fluorescence Test

We also demonstrated that PCL as the bonding medium does not adversely influence basic biological tests such as protein detection. Another simple protein test shown in Figure 7, the anticipated blue color develops only when the indicator is reacted with protein (1). Chips with very simple design can be fabricated using PCL as the bonding media (3), which then can be used to detect the presence of protein.

Figure 7. PCL Coomassie Test

Figure 8 demonstrates that paper microfluidic devices can be produced by direct writing the channel patterns with a laser on a piece of filter paper with a PCL backing. Samples were introduced into the hydrophilic microchannels by force of capillary action.

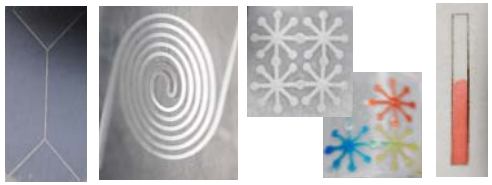


Figure 8. Paper Microfluidics With PCL

CONCLUSIONS

1. A simple fabrication process, using only a knife plotter, a thermal press, and a thin film of PCL as the bonding medium, was shown to be a low cost, rapid approach for production of microfluidic chips, including multiple-layer and hybrid microchips.
2. It was demonstrated that PCL can be modified to include functional groups, such as amines, which can be further utilized to attach molecules of choice. And PCL itself did not adversely influence biological tests, such as protein detection.
3. It was shown that PCL is an ideal material for production of low-cost, disposable paper microfluidic devices.

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The first two authors contributed equally to this work.