DYNAMICALLY PROGRAMMABLE PARYLENE-C BONDING LAYER FLUORESCENCE FOR RE-WRITABLE DATA STORAGE ON A MICROFLUIDIC CHIP

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ABSTRACT

Wafer bonding using parylene-C to Si, SiO_2 and SiN surfaces has recently been shown to enable high pressure-resistant microfluidic devices with metallization and CMOS-integration capability [1-3]. Here, we report characterization of intermediate parylene-C bonding layer fluorescence (iPBLF) and its use as an on-chip medium for data storage by dynamic programming of iPBLF intensity, using alternating exposure of parylene-C to UV and Green light. This technique allows data on the microfluidic chip to be read, written and erased by a fluorescent microscope and this virtually at no extra cost.

KEYWORDS

Programmable fluorescence, parylene bonding, lab-on-a-chip data storage

INTRODUCTION

Industrial applications of microfluidic devices will bring additional automation challenges, where the functionality, layout and protocol parameters would need to be stored and adjusted with changing versions of microfluidic chips. An ideal on-chip memory should introduce no additional steps or materials in microfabrication, be easily programmable and readable by standard equipments both during production and utilization. Fluorescence of the polymer materials used during fabrication of the microfluidic devices is, in fact, an ideal candidate, since many microfluidic devices require fluorescent imaging systems for their operation. We have recently shown wafer bonding with parylene-C layers to Si, SiO_2 and SiN surfaces to fabricate microfluidic devices where parylene-C is used both as a bonding medium and structural layer to form microfluidic channels (see Figure 1) [1-3]. Although fluorescence of as-deposited parylene-C films under UV light has been studied previously [4-6], iPBLF can behave significantly different due to the changes in the polymeric structure induced by temperature processing during bonding [5] and vacuum-like conditions in the bonding stack.

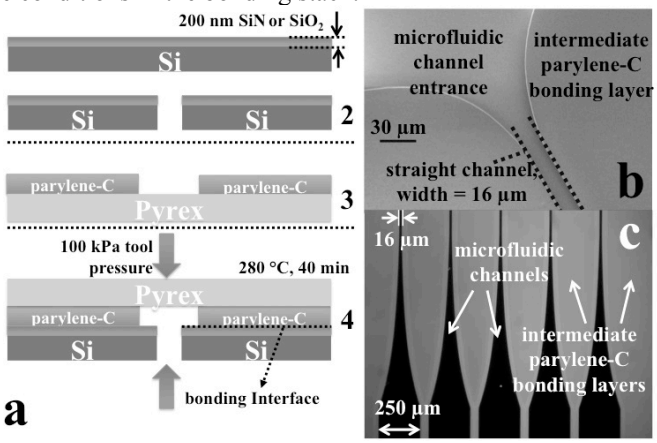

Figure 1 - Microfluidic devices fabricated using parylene-C to SiN (or SiO_2) bonding. (a) Illustration of the fabrication process. 1) Si wafers with 200 nm thick SiN were taken. 2) Fluidic inlet holes were opened in one silicon wafer by Deep RIE. 3) Channels were etched in 10 µm thick parylene-C using RIE via an amorphous Si mask. 4) Wafers are bonded at 280 °C under vacuum during 40 minutes while applying 1000 mbar tool pressure. (b) Shows a SEM image of parylene-C just before bonding, where the etched trenches correspond to microfluidic channels and parylene-C acts as an intermediate bonding layer in a subsequent bonding process. (c) Fluorescent image of a bonded device observed with UV excitation (310 – 390 nm)/blue emission (420 nm -) filters, where the dark and fluorescent regions correspond to microfluidic channels and intermediate parylene-C bonding layer fluorescence (iPBLF) respectively

EXPERIMENTAL

Here, we first characterize and then exploit iPBLF to store and rewrite data on a microfluidic chip using a fluorescent microscope. In order to determine the effect of the bonding process on iPBLF, we first experimentally quantified the fluorescence in patterned parylene-C structures before and after bonding, as well as at the cross-section of the bonding stack. Figure 2 shows the experimental results using 6 different fluorescent filter sets corresponding to common fluorescent markers in the market. Although the iPBLF intensity is increased in all cases after the bonding process, the results suggest that it is only significant when observed at UV/Blue and Green/Red channels. Therefore, we subsequently analysed the dynamic behaviour of iPBLF intensity when illuminated with excitation light of these channels.

978-0-9798064-5-2/µTAS 2012/$20©12CBMS-0001

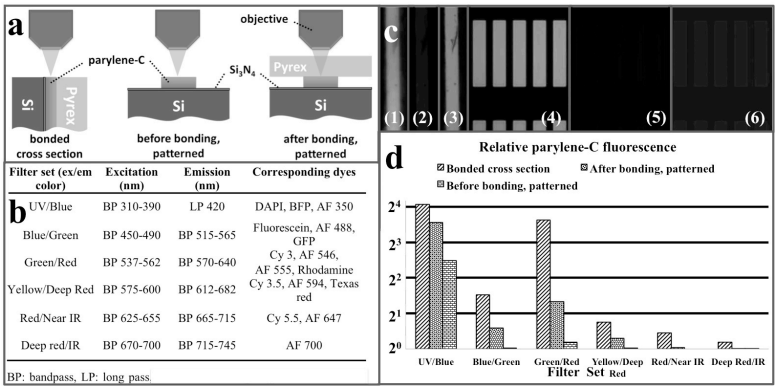

Figure 2 - Characterization of intermediate parylene-C bonding layer fluorescence (iPBLF) before and after bonding. (a) Schematic diagram illustrating the experiments to characterize the effect of bonding on iPBLF. (b) Excitation and emission wavelengths of the filter sets used in this study and corresponding commercial dyes. (c) Gray-scale fluorescent images (1), (2), (3) of parylene-C at diced device cross-sections; (4), (5), (6) show patterned parylene-C after bonding, as observed with the UV/Blue, Blue/Green and Green/Red filter sets, respectively. (d) Plot of iPBLF intensity relative to the background, with most significant appearance in the UV/Blue and Green/Red channels.

Figure 3 shows the time response of iPBLF under constant illumination with UV (310 – 390 nm) and Green (537 – 562 nm) light, where it can be seen that the variation of fluorescence observed in the Green/Red channel behaves complementarily under UV and Green illumination. Figure 4 demonstrates the dynamic programming of iPBLF intensity fluorescence using illumination with alternating UV and Green light, which allows digital data to be written and erased on the iPBLF layer.

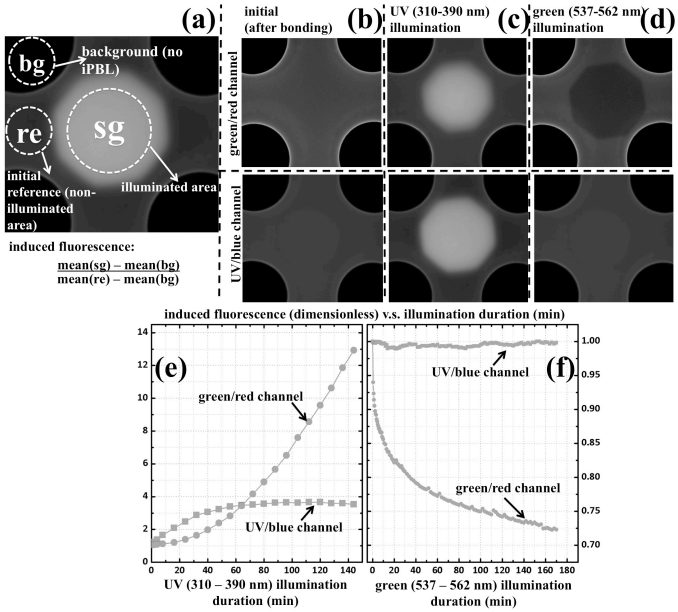

Figure 3 - Time response of iPBLF under continuous illumination with UV (310 – 390 nm) and Green (537 – 562 nm) light. Here, "illumination" corresponds to a long exposure (>1 min) to a given wavelength, inducing fluorescence (or bleaching it) for writing (or deleting) data on a memory spot. In contrast, "induced fluorescence" corresponds to taking an instantaneous (<0.5 s) picture in a fluorescence channel. (a) "Induced fluorescence" and calculation of the induced fluorescence. (b-d) Fluorescent images showing the iPBLF "induced" in the UV/Blue and Green/Red channels: (b) initially after bonding without any "illumination", and after "illumination" with (c) UV and (d) Green light, showing that the UV can be used to increase fluorescence, whereas Green light can be used to decrease it. (e) and (f) show the plots of induced fluorescence vs. "illumination" duration for UV and Green light, respectively. The plots suggest that the iPBLF variation observed in the Green/Red channel has an opposite trend when the spot is illuminated with either UV or Green light, while iPBLF observed in the UV/Blue channel cannot be reversed.

CONCLUSIONS AND OUTLOOK

We demonstrated data storage on a microfluidic chip by programming intermediate parylene-C bonding layer fluorescence. We anticipate that dynamically programmable iPBLF constitutes an ideal candidate for use as an on-chip memory medium to overcome possible automation challenges of microfluidic devices by storing relevant data like expiry date and layout information. This can also be useful in many applications requiring optical detection of channel dimensions and positions, displacement analysis and other automated microscopy applications.

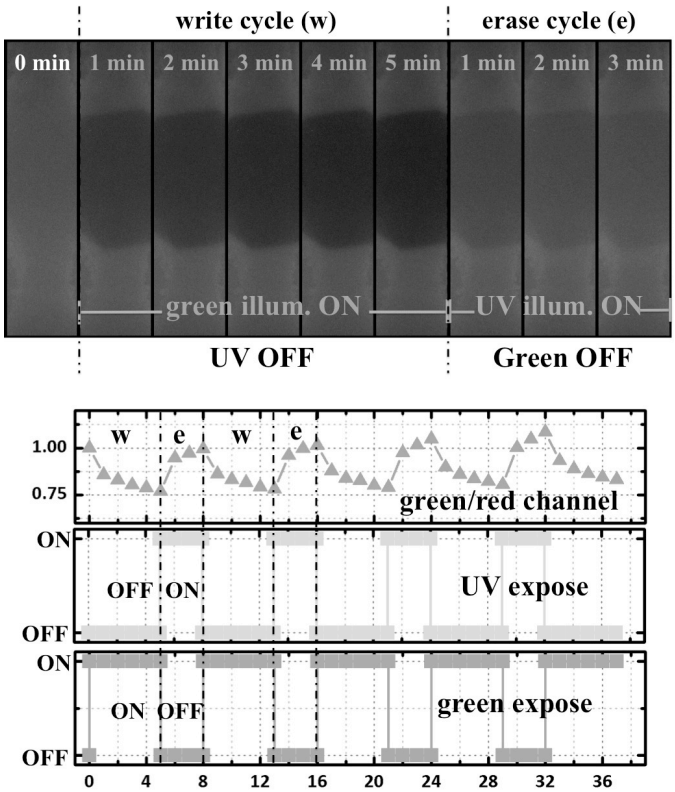

Figure 4 - Dynamic programming of iPBLF with alternating "illumination" using UV and Green light. Top: Time-lapse pictures of a memory spot write-erase cycle. The decrease upon Green illumination during 5 min is used to "write" while subsequent UV illumination of the same spot during 3 min is used to "erase" information by reversing the effect. Bottom: Timing sequence of multiple "write" and "erase" cycles at the same spot with 8 min period.

APPENDIX

Imaging conditions: *Microscope:* Zeiss AxioImager.M2; *Objective:* Zeiss Plan-Neofluar 20x, 0.4 N.A. coverslip-corrected to 0.55 mm; *Light source:* Zeiss HBO 50/AC; *Camera:* Zeiss AxioCam MRm; *Camera exposure:* 12 ms for UV/blue channel and 500 ms for green/red channel.

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