Maskless Plasma Patterning of Fluidic Channels for Multiplexing Fluid Flow on Microfluidic Devices

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Abstract:

A novel selective surface plasma treatment method based on spatially confined electron beam-induced plasmas enhances fluid flow in microfluidic device channels without requiring patterning, offering the possibility of significant cost reductions in the fabrication of these devices. We demonstrate equal distribution of flow along several paths on PMMA substrates. Flow enhancement is enabled by the incorporation of hydrophilic moieties on an initially and otherwise hydrophobic surface. X-ray Photoelectron Spectroscopy (XPS) identifies significant and persistent addition of hydrophilic C-O and C=O functionality.

Background:

Microfluidic devices use a single chip to combine multiple functions in the preparation and detection of an analyte. Hydrophilic surface modification increases performance by improving the velocity, uniformity and consistency of the fluid flow. Miniaturization and low cost fabrication are key criteria driving point of care diagnostics.

Conventionally, selective micro- and nano-meter scale surface treatment requires masking and complex processing, which increase the device costs. On the other hand, eBIPs (electron-beam induced plasmas), which have diameters ranging from < 1μm to 1000s of μm and are generated by transmitting a high energy e-beam into ambient atmosphere provide a maskless (i.e., low cost and high throughput) method for selective hydrophilic treatment of microfluidic channels (Fig. 1). Moreover, the ability to arbitrarily define hydrophilic patterns on a surface creates the possibility to fabricate virtual channels without the necessity of physical channels and hence to further reduce device costs

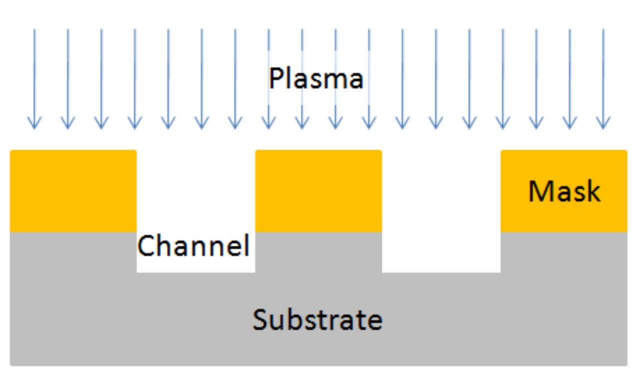

Fig. 1a: A conventional selective plasma exposure requires subtractive masking or shadow patterning.

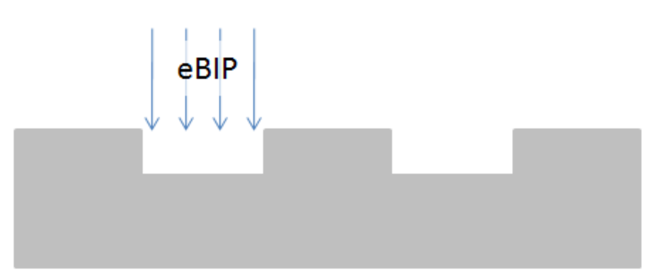

Fig. 1b: Selective plasma exposure using electron-beam induced plasmas (eBIP) – no masking required

Experimental Details:

The eBIP system is a compact module that emits a 5-30 keV electron beam into ambient atmosphere. Both top and bottom surfaces of the microfluidic channels are exposed to the eBIP

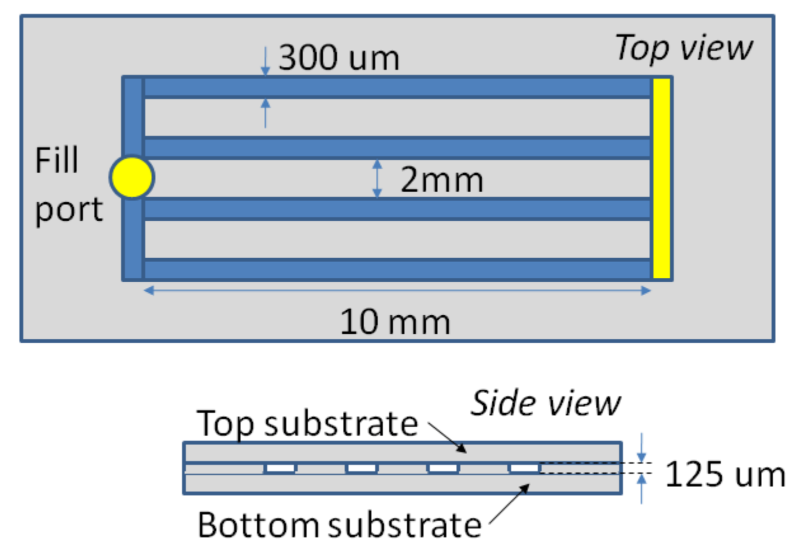

Fig. 2: Schematic of the PMMA test fluidic device.

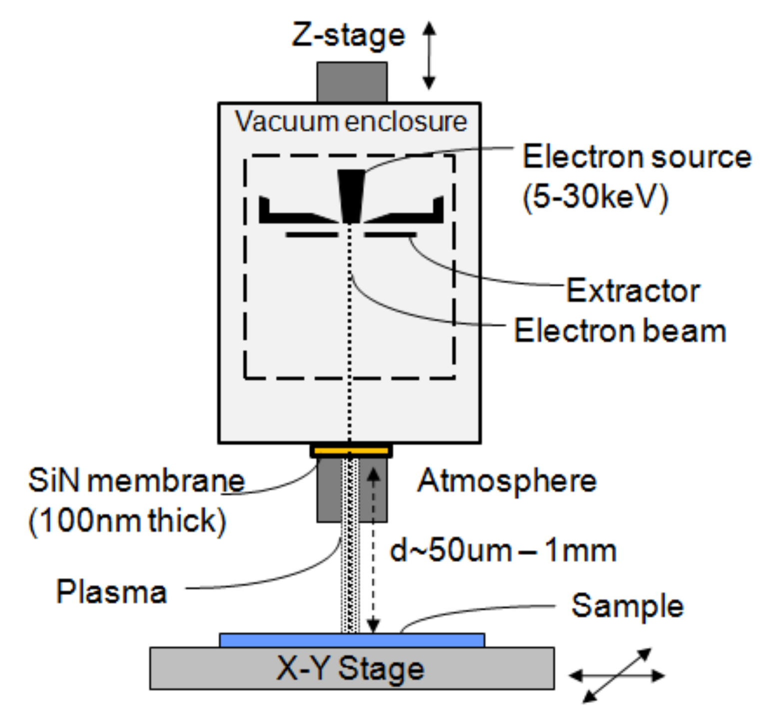

Fig. 3: Apparatus schematic

Fluid tests:

We applied several μL of 70 dyne/cm colored dye ink to the microfluidic devices before and after eBIP treatment of the channels and observed the fluid propagation. Before eBIP exposure, no flow is observed. After eBIP exposure, fluid flow can be unambiguously observed (Fig. 4b). The flow velocity is similar (13 mm/s) in all 4 branches. Furthermore, eBIP processing results in a clear decrease in the contact angle (Fig. 5), indicating improved hydrophilicity

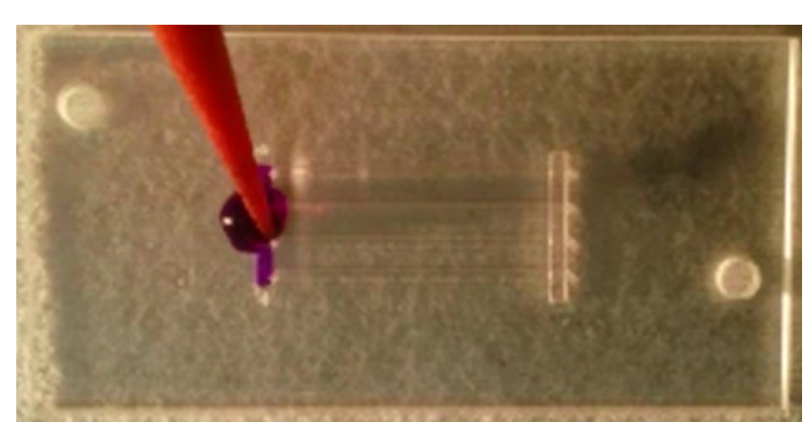

Fig. 4a: Photograph showing no fluid propagation in channel of an untreated PMMA device.

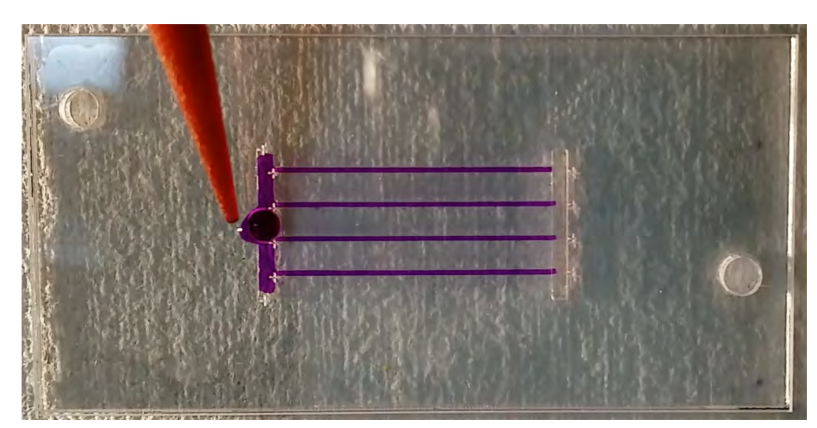

Fig. 4b: Photograph of fluid propagation through eBIP exposed channels.

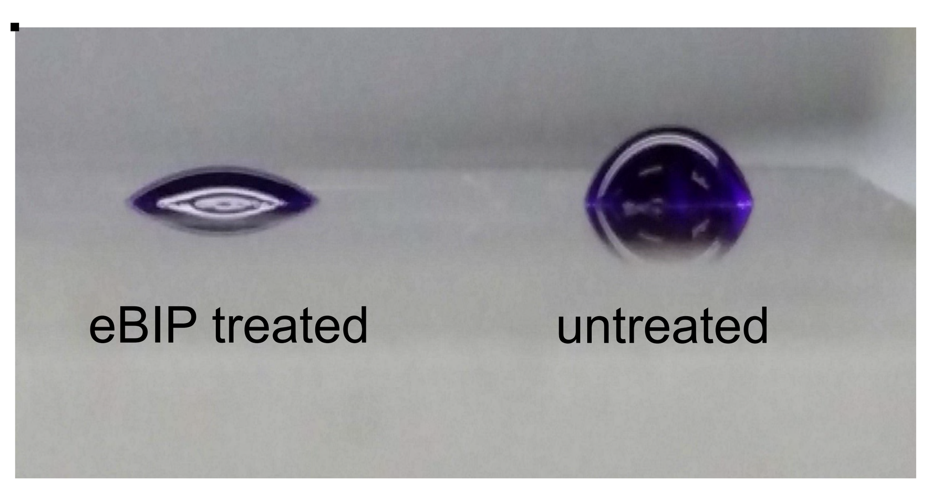

Fig. 5: Photograph of 70 dyne/cm ink droplets on eBIP -treated and untreated PMMA, showing a contact angle decrease after eBIP exposure

Chemical Analysis:

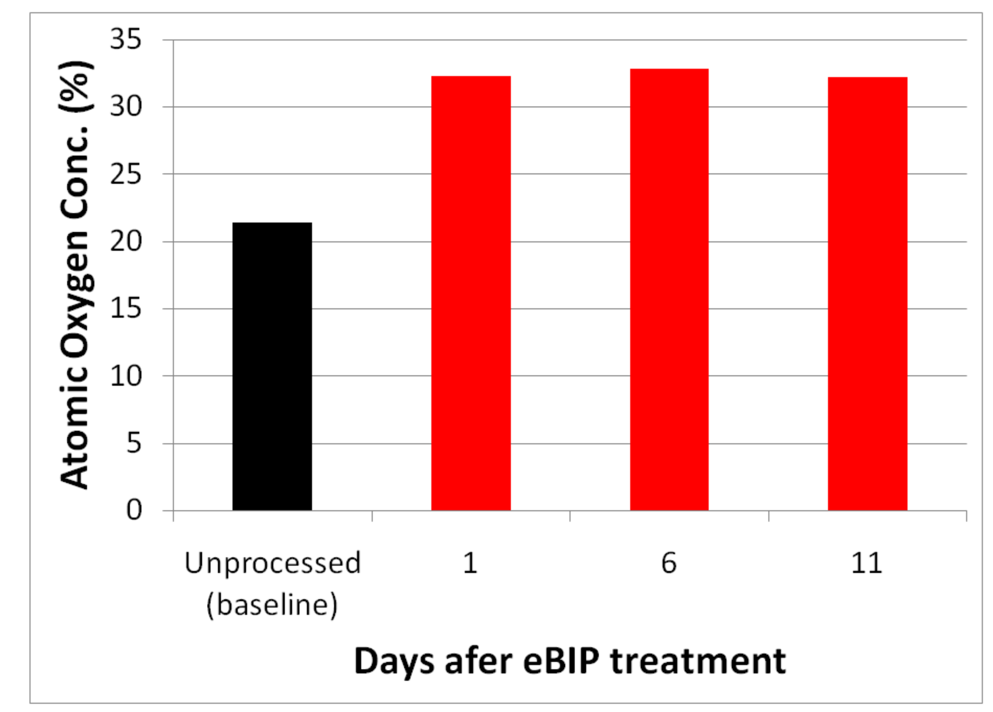

Fig. 6: Elemental oxygen concentration as determined by XPS analysis of PMMA substrates as a function of time after eBIP treatment. Results obtained on an unprocessed substrate are shown for comparison. Surface analysis by Evans Analytical Group

XPS was used to quantify the chemical state of the PMMA surface. The data (Fig. 6) shows that the oxygen concentration increases from 21% to 32% upon eBIP exposure. This increase is consistent with results obtained using large area low pressure plasma treatment.

XPS measurements of the oxygen concentration at increasing times after eBIP processing (with samples stored in controlled conditions) show no significant changes over a 11 day period, suggesting the surface modification is persistent.

The results of high resolution XPS on BIP-treated samples (Table I) show that elemental Oxygen is evenly distributed between C=O and C-O groups (Table I). These compounds provide stable hydrophilization of the PMMA surfaces.

Table I: Assignment of the Oxygen functionality on eBIP-treated PMMA Surface analysis by Evans Analytical Group

	C=O	C-O
Treated PMMA	49 %	51 %

Conclusion:

We have developed a compact, electron-beam based, atmospheric plasma system that enables selective treatment of microfluidic channels without requiring patterning. We have demonstrated that eBIP exposure results in clear, uniform improvements in fluid propagation in the channels. These improvements are attributed to attachment of C-O and C=O groups, which provide stable hydrophilization, to the surface