Integration of a predictive model with microfluidics fabrication using a 193 nm excimer laser source shaped by an intelligent pinhole mask

OÉ Gaillimh
NUI Galway

Kevin Conlisk and G. M. O'Connor
National Centre for Laser Applications, National University of Ireland, Galway

National Centre for Laser Applications

Lab-on-a-Chip European Congress 2010

Introduction

With the advent of polymer microfluidics, lasers have become an important tool for the rapid production of devices. In the context of device fabrication, laser micromachining is characterised by low throughput but high adaptability. It is this adaptability that can be exploited to produce complex planer devices. Generally, the complexity of the geometry achievable is related to the control that can be exhibited over the fabrication process. By using a reconfigurable mask, in the form of an intelligent pinhole, some of the limitations associated with these techniques can be overcome.

The aim of this report is to demonstrate the use of our prediction model to simulate analyse and refine a microchannel geometry prior to fabrication. The use of CFD analysis provides quantitative feedback on the modeled structures.

Background

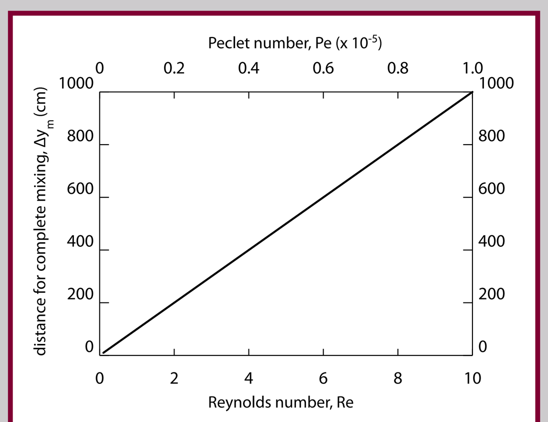

Fig. 1 Evolution of the mixing length with Re and Pe.

An area of microfluidics generating great interest is that of mixing within a laminar flow network. For straight channels, of constant cross section, the type of flow can be characterised by the Reynolds number, Re. This is the ratio of inertial forces to viscous forces, and can be defined as, Re = ρuL/η, here *ρ*, represents the fluid density, *u*, the fluid velocity, *L*, the characteristic length, and *η*, the fluid viscosity. Microfluidic devices are characterised by low Reynolds numbers, Re < 2100, which gives rise to laminar flow. At these low Re values, chaotic advection that exists at the macro scale vanishes, and two streams moving side-by-side in a microchannel will mix by diffusion alone. If the diffusion process is fast compared to the advection of the fluid down the channel then effective mixing can still be achieved. However, the Peclet number, which is the ratio of these two processes, is typically large in microfluidic networks, Pe = uL/D, where *D* is the molecular diffusivity. Consider the time taken for a particle to diffuse across the channel, $\tau_D \sim L^2/D$, an estimate for the distance required for mixing, Δy_m, can be established, $\Delta y_m \sim uL^2/D \sim Pe \times L$ [1].

Experimental Methods

The laser workstation comprises of a 193 nm excimer laser shaped by the intelligent pinhole mask (Fig. 2). The complexity of the masks operation, coupled with the laser parameters, scanning stage renders it difficult to predict channel geometries when using a large array of inputs. This has lead to the need for a prediction model (Fig. 3) to visualise the resulting channel geometry prior to fabrication. Table 1 lists the properties considered when developing the prediction model.

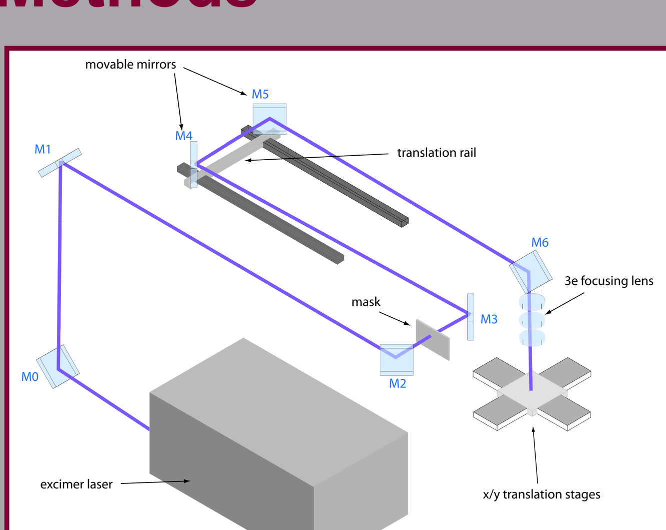

Fig. 2 Experimental setup indicating the position of the mask in the laser beam-path.

Table 1 Prediction model input considerations.

Initial inputs	Mask select	Laser parameters	Output result
pulse energy mask size	offset waveform amplitude frequency phase	repetition rate scan speed scan distance scan direction	visualisation measurement export

Each edge of the mask may be varied independently resulting in a total of 15 variables for the 'Mask select' inputs alone. The model uses the equation shown opposite to calculate the channel depth; here M_s is the instantaneous mask size, *f*, the laser frequency, v_s, the substrate velocity, and, *r*, the ablation rate of the material.

$$Ch_d = \frac{M_s \times f}{v_s} \times r$$

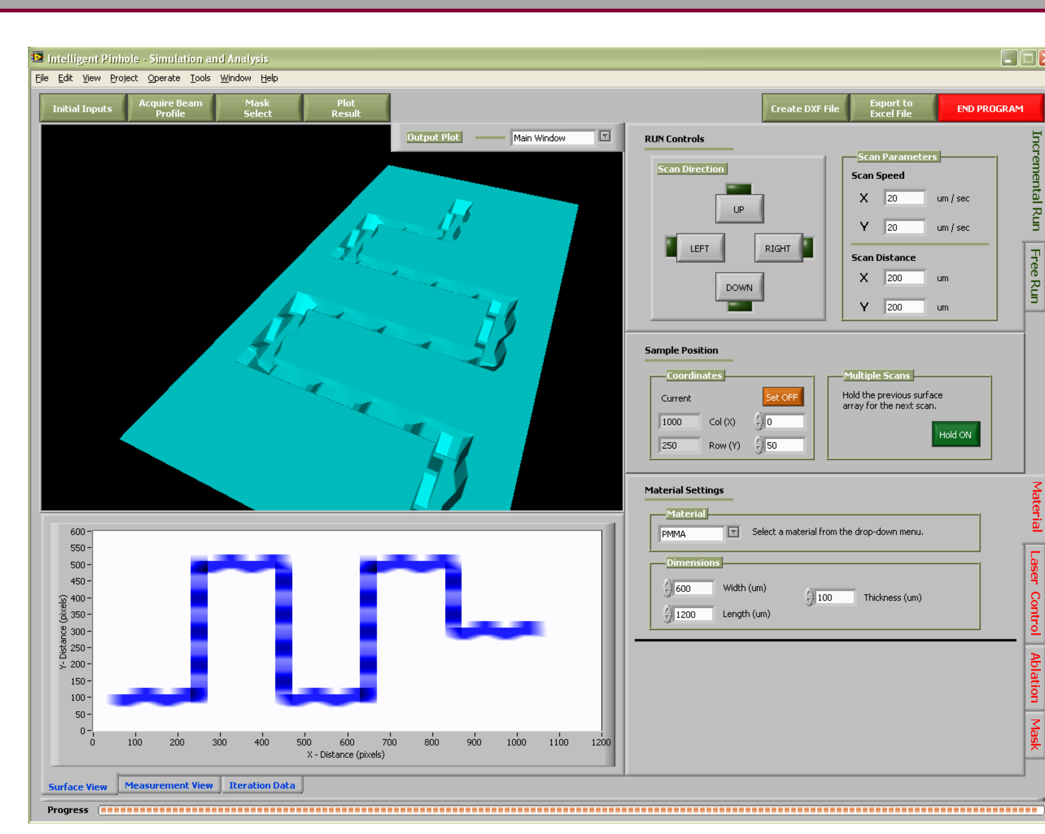

Fig. 3 Prediction model user-interface.

During the CFD analysis the continuity equation, 1, and Navier-Stokes equation, 2, are solved in the case of an isothermal incompressible fluid. The distribution of the species concentration is obtained by solving the convection and diffusion equation, 3. The concentration is normalised to values of 1 and 0 at the input to the microchannels.

$$\nabla \cdot u = 0 \quad (1)$$

$$\rho u \cdot \nabla u = -\nabla p + \eta \nabla^2 u \quad (2)$$

$$\nabla \cdot (-D \nabla c_s) = u \cdot \nabla c_s \quad (3)$$

Results and Discussion

Fig. 4 shows a comparison of geometries predicted with the model to that fabricated with the pinhole. Validation of the prediction model shows a surface (x/y) error of +/- 5% with a depth (z) error of +/- 8%. Therefore, the prediction model may be used for quantitative analysis of geometries prior to fabrication.

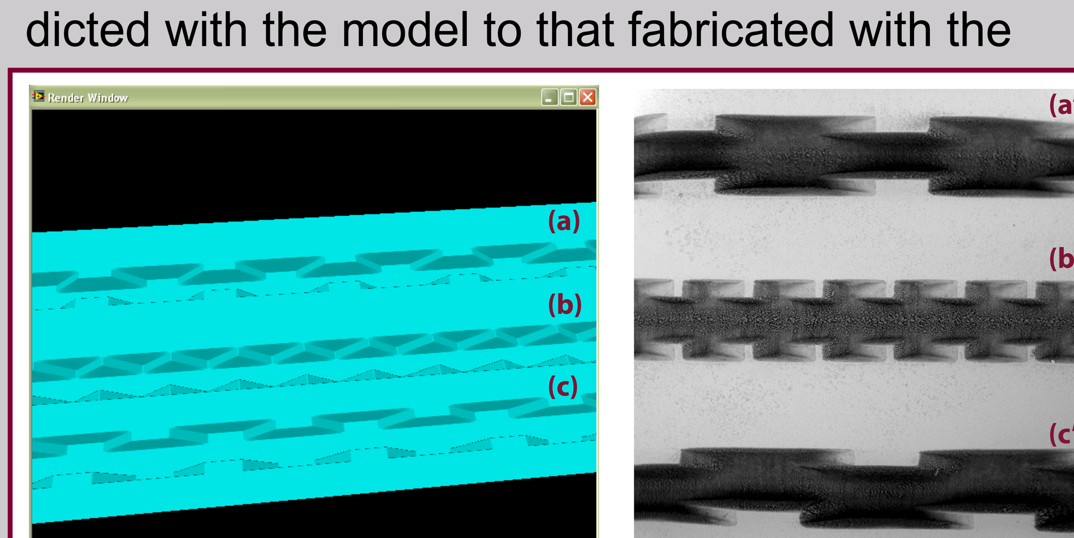

Fig. 4 Comparison of predicted geometry (left) with SEM image of fabricated geometries (right).

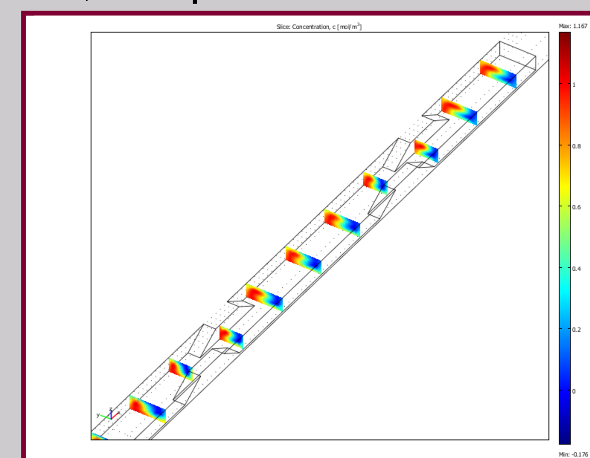

Fig. 5 Mixer overview.

Using the prediction model a mixer geometry was developed (Fig. 4(c)) and exported for CFD analysis (Fig. 5). Obstacles we placed in the path of the flow to encourage folding of the two streams. In a planer channel with the same Peclet number (Pe = 1 x 10^4) the length required for mixing, Δy_m, is estimated to be ~ 60 cm. Fig. 6 shows slice plots of the species mixing as the two streams proceed along the channel. After 10 mm the mix quality is at ~ 40%, indicating a Δy_m < 30 mm for this channel layout. This is a 95% improvement over the planer channel with no obstacles.

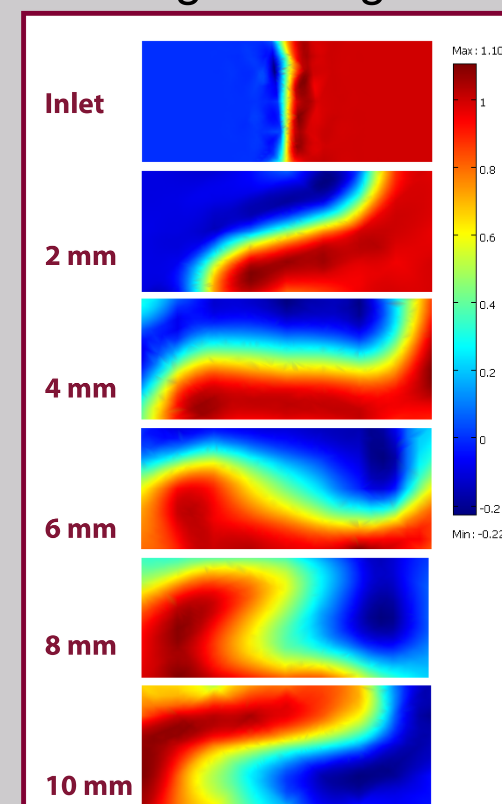

Fig. 6 Cross-sectional plots at increasing distance down the microchannel showing species distribution.

The geometry was subsequently fabricated on a PMMA substrate shown in the SEM image, Fig. 4(c'). An interesting feature is the transverse folding of the flow imposed by the sidewall baffles in the microchannel. Greater mixing efficiency may be achieved by altering the dimensions of these baffles or their position and number within the channel.

Conclusions and Future Work

• A micromachining platform, with integrated prediction model, has been demonstrated for simulation and fabrication of microfluidic geometries.

• Using the prediction model, different geometry configurations may be explored prior to the fabrication step.

• CFD analysis of the resulting geometries has indicated they may perform well as micromixers by reducing the overall channel length required for mixing.

Future work will focus on producing higher performance mixers using the prediction model and intelligent pinhole. The geometries will be analysed using CFD at a range of Pe numbers for an estimation of Δy_{90}. Further characterisation will be provided by fabricating these structures, capping, and testing them using a combination of fast camera and confocal microscopy techniques.

REFERENCES:
[1] A. D. Stroock, S. K.W. Dertinger, A. Ajdari, I. Mezic, H. A. Stone, and G. M. Whitesides, "Chaotic mixer for microchannels," Science, vol. 295, pp. 647–651, January 2002.

CONTACT INFORMATION:
Kevin Conlisk
Ph.D Student
National Centre for Laser Applications
National University of Ireland, Galway

Mail: kevin.conlisk@nuigalway.ie
Tel: +353 91 493595
Web: www.ncla.ie
www.nuigalway.ie/lighthouse

NDP National Development Plan
European Union Structural Funds
Enterprise Ireland
This work was supported by grant CFTD/2005/309