euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

# Precision manufacturing of polymer micro-nano fluidic systems

Matteo Calaon[1], Guido Tosello[1], Krystian Meresiński[1], Jorgen Garnaes[2], Hans N. Hansen[1]

[1] *Technical University of Denmark, Department of Mechanical Engineering, Lyngby, Denmark.*
[2] *Danish Fundamental Metrology, Nano scale division, Lyngby, Denamrk.*

*mcal@mek.dtu.dk*

**Abstract**
Lab-on-a-Chip (LoC) technologies require the possibility of fabricating devices which include micro down to sub-micrometre features with high production rate and low cost. In the present study precision injection moulding is performed using a COC Topas 5013 L10 polymer to produce LoC devices for DNA barcoding with functional features in the 100 nm to 10 µm range. Replication quality of produced features (from nickel to polymer) was assessed by calibrated atomic force microscope (AFM) measurements performed on multiple nanochannels test structures arrays placed at different positions in the sample. Design of experiment (DOE) was adopted to characterize the replication fidelity of produced polymer features. Results have shown the possibility of performing quality control of micro- and sub-µm features, taking into account the polymer shrinkage, depending on process conditions at both micro and nano dimensional scales.

**Keywords:** Lab-on-a-chip, nano metrology, precision injection moulding.

## 1. Introduction

A fundamental aspect to be considered, for LoC future commercial exploitation, is the required tolerance for functionality definition and verification which represents a challenge at the nano dimensional scale [1]. For example, as far as nano channels for DNA screening are concerned, a tolerance down to ± 10 nm for a channel depth of 100 nm is required to ensure screening effectiveness with improved detection resolution. To validate the precision manufacturing of micro-nano fluidic systems, an integrated quality control of the produced polymer parts to quantify the replication degree from the master to the replicated parts is necessary. Therefore, finger print test structures representative of sensitive features (i.e. nano channels gratings of the LoC application [2]) were manufactured on different positions of a nickel shim used for later injection moulding of the disposable polymer nano fluidic systems(see Figure 1).

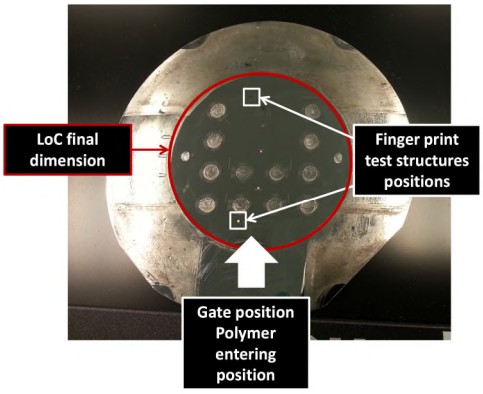


**Figure 1.** Nickel shim used for experimental injection moulding with integrated test structure fabricated over different positions aside of the LoC functional design.

Test structures allowed measurements relocation of corresponding measuring points on the produced polymer parts. The effects of packing pressure and different part parameters on final part quality were studied. The pitch dimensional variation from polymer to nickel micro/nano structures was quantified. Data management system for information-based part quality control enabling robust and fast measurement analysis was implemented.

## 2. Experimental set up

The DEEMO process (acronym for dry etching electroplating and moulding) [3] was employed to fabricate the shim used in the current investigation. Functional LoC channels/structures were fabricated in the central part of the shim while finger print test structures were positioned at two different distances from the polymer flow entrance position (see figure 1). Finger print test structures in the form of nano channels (with the following target design dimensions: height = 110 nm, width = 300 nm; pitch = 1000 nm; length = 450 µm) were designed and fabricated to match dimensions of functional nano channels grating located in different positions of the device. The polymer part where produced on an ENGEL injection moulding machine with screw diameter of 18 mm and clamping force of 450 kN. Injection moulding machine settings, see Table 1, were based on: results of optimization procedures presented in [4], equipment capabilities and process reliability.

**Table 1.** Injection moulding process settings.

| Injection moulding process parameters | |
|---|---|
| Inj. Flow rate | 10 $cm^3/s$ |
| Packing time | 7 s |
| Mould temperature | 115°C |
| Melt temperature | 250°C |

A statistical design of experiments (DOE) based on a generalized full factorial design including $2^3$ x 3 = 24 moulding

experiments was carried out. Three output parameters were selected: channel side wall direction (i.e. ascendant, descendant), test structures distance from the gate, and pitch distance over two different packing pressure levels were investigated to derive optimal process settings that could improve replication quality.

### 3. Replication fidelity assessment

Width deviations measurements results were based on $W_{dev} = (W_{polymer} - W_{Nickel})$ measurand that quantified degree of replication between nickel master geometries and moulded polymer features produced within the DOE. Calibrated atomic force microscope (AFM) measurements quantified the finger print test structures dimensions on produced nickel shim and on mirrored structures over the moulded polymer parts ensuring exact measure repositioning (Figure 2a). Scanned areas of 10x10 $\mu m^2$ on both substrates were analytically processed by a Matlab code enabling nano channels gratings pitch identification (Figure 2b) and their dimensional measurements calculation (Figure 2c).

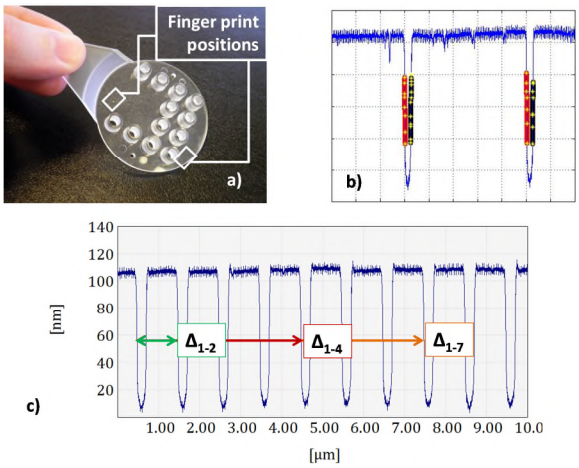


**Figure 2.** a) Produced polymer chip; b) software interpolation of the groove slops with identification of ascending (black dots) and descending (red dots) points; c) illustration from polymer nano channels cross section of different pitches distances quantified in the analysis.

The code enabled the automated calculation of pitch distances at the same trenches depth/height level in order to remove possible errors due to operator influence and manual post processing. Measurements of the different polymer pitches were compared with corresponding pitch distances in the master nickel shim. Each polymer and nickel pitch distance represents average value of 3 measurements repetitions. Deviation from the full replication was quantified for the different DOE experiments.

### 4. Results and discussion

The results are summarized in the main effect plots (Figure 3). Mean values of different measurements results ($W_{dev}$) corresponding to different level settings are compared. Results from the different pitch measurements taken on ascending and descending single trenches direction (in respect to AFM scanning direction) shown no significant effect on the final measurements polymer pitch variation, suggesting no influence from AFM tip folding effect. As well as for packing pressure, influence of different pressures levels applied during the test showed no significant effect on the final geometries fidelity. The trend suggests that the polymer when replicating the nano channels solidifies very rapidly becoming imperceptible to pressure variation when the mould cavity is completely filled. On the other hand no significant effect of measurements results performed on test structures at different distances from the gate indicate that the polymer melt reach the end of the cavity with similar melt conditions created at the gate location. Significant effect of the nano channel deformation along the x scanned direction is given by the increased pitched distances. The graph shows how conformance between polymer to nickel geometries decreases proportionally with the distance from the first reference trench. The polymer linear shrinkage calculated from the width deviations is 1,0 ± 1%.

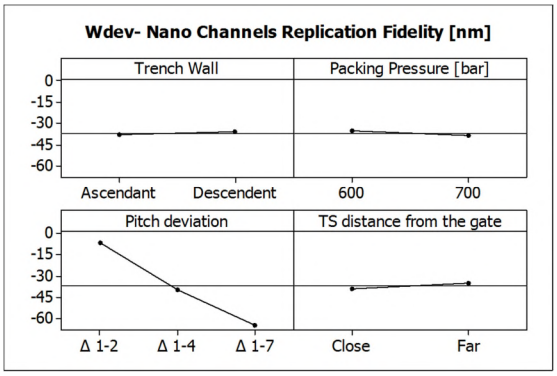


**Figure 3.** Main effect plot for test structures (TS) geometries produced by injection moulding depending on process and part parameters.

### 5. Conclusion

The possibility to fabricate LoC devices with fast and cost-effective process chain will ultimately enable these analytical technologies to be accessible to a broader range of applications. In this direction the present study investigates the possibility of controlling critical functional structures of a LoC device for DNA mapping sensing purposes. The test structures, fabricated using the DEEMO process, allowed AFM calibrated measurements relocation over master nickel structures and replicated polymer parts. DOE was employed to optimize the device part quality and to identify different effects on polymer dimensional variation ($W_{dev}$). A Matlab code enabling fast data management (i.e. AFM scanned areas over different substrates) and pitch calculation was implemented. Results showed no effect of trench wall (i.e. ascendant, descendant), packing pressure and features distance from the gate position indicating optimal process settings window for the produced polymer parts. Moreover significant effect of polymer shrinkage depending by different pitch distances was quantified. Test structures prove to be a valuable tool for polymer micro-nano fluidic systems quality assurance, process control and material characterization.

**References**


[1] Hansen H.-N., Carneiro K., Haitjema H., De Chiffre L., 2006, Emerging trends in surface metrology, *Annals of the CIRP*, **55**/2:721–743.

[2] Mikkelsen M.-B., Reisner W., Flyvbjerg, H., Kristensen A., 2011, Pressure-Driven DNA in Nanogroove Arrays: Complex Dynamics Leads to Length- and Topology-Dependent Separation, *Nano Letters*, **11** 1598-1602.

[3] Tanzi S, et. al., 2012, Fabrication of combined - scale nano- and microfluidic polymer systems using a multilevel dry etching, electroplating and molding process. J Micromech. Microeng. **22**: pp 11.

[4] Calaon M., et.al.,2013, Microfluidic Chip Designs Process Optimization and Dimensional Quality Control, J. of Microsys. Techn., pp. 10 (**DOI**) 10.1007/s00542-013-2025-3.