# Characterisation of 3D printers using fibre Bragg gratings

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## ABSTRACT

The extrusion nozzles of three low cost desktop 3D printers are characterised using optical fibre Bragg gratings. Temperature profiles show remarkably consistent distributions pointing to operation as good quality micro-furnaces potentially not only for 3D printing but also optical fibre drawing.

**Keywords:** 3D printing, FBGs, fibre Bragg gratings, micro-furnaces, hot zones

## 1. INTRODUCTION

3D printing is on track to being the single most major disruptor of manufacturing technology, already widely applied to many industries, with low desk top printers leading the fore of prototyping and potential consumer use. For this reason we have focused on demonstrating the power of desktop printing to undermine existing fabrication technologies such as optical fibre preform manufacture [1-3], recognising full well the demonstrations in polymer today will be superseded by demonstrations of desktop manufacture of optical glass preforms as printing with glass soon comes to fruition. Although the quality and confinement would appear limited by the printing resolution of current low-cost desk-top 3D printers, this work points to a major revolution in optical fibre manufacture. Amazingly, despite these tremendous impacts, there has been little work done on basic characterisation of the technology and an assessment of its potential and limitations. How good are these printers? How well controlled is the heating profile? Do they seriously compete with million-dollar fabrication facilities with stringent control?

In this paper, a careful study of the thermal properties of three commercial low-cost 3D printers is undertaken using fibre Bragg gratings. The centerpiece of a 3D printer is ultimately its heating element and its operation as a microfurnace from which filament material is deposited. Understanding their performance is critical for assessing applications such as preform manufacture and more.

## 2. EXPERIMENTAL

### 2.1 3D printers

The three desktop printers are summarised in Table 1. They span the budget printer to intermediate low cost printer, all below $AU 5000. To compare between printers, the Redback (delta) [4] conditions were chosen to enable similar printing of transparent polymers to that of the Flashforger (*xyz*) [5], which required a printing temperature around $T$ = 230 $^0$C. These two are dual nozzle printers whereas the third printer, from Zortrax [6], is single nozzle xyz printer. All these printers have an in-built thermocouple (Type $K$) to measure and set temperature conditions for the printing processes so accuracy in this is extremely important. Ordinarily the manufacturer would use an infrared gun to estimate and calibrate the temperature at a fixed point. Whilst this might reasonably be accurate within a few degrees, it does not directly measure the temperature and its distribution inside and along the extrusion nozzles (internal $\phi$ = 0.4 mm). Given the critical importance of both temperature and temperature distribution in the ability to control printing with high precision, we have characterised the internal temperature profile of the extruders.

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Table 1. Summary of the 3D printers characterised in this work.

| Model | Type | Source | Cost ($AU) | nozzle # | $T_{max}$ (°C) |
|---|---|---|---|---|---|
| Redback 2 | Delta | 3DBrink (Australia) | $3500 | 2 | 280 |
| Dreamer | xyz | Flarshforge (China) | $1490 | 2 | 300 |
| M200 | xyz | Zortrax (Poland) | $2600 | 1 | 320 |

### 2.2 Fibre Bragg grating characterisation

To characterise this internal profile, silicate optical fibre Bragg gratings ($\lambda \sim 1547$ nm, $R$ ~35 dB, FBG – $L$ = 2 mm) were directly written using ArF 193 nm laser light through an optical phase mask into standard silica based telecom fibre (SMF28). Thermal stabilisation at higher temperatures ($T$ = 300 $^0$C, $t$ = 15 mins) allowed higher temperature performance up to 300 $^0$C [4].

The FBG is inserted into the nozzle tip using each printers own translation stages. For the Redback 2, it is the nozzle that is moved by the delta designed tracks. This therefore involves moving the nozzle itself along the FBG propped up from the base (resolution ~ 2 mm/step). Both the Flashforge and Zortrax are *xyz* stage based printers that move the stage where a sample is printed so the FBG is instead moved into the extruder nozzles (resolution ~ 2 mm/step) using these stages. All are controlled via the software of each printer. Of the three printers, the Redback 2 and Flashforge have dual (two) extruders with similar measured extruder body lengths, $L = (2.0 \pm 0.1)$ cm whilst the Zortrax, with a single extruder nozzle, is longer, $L = (2.6 \pm 0.1)$ cm. A reasonable expectation would be that the measured temperature profile will reflect this. Experimentally, the Bragg wavelength shift, $\Delta\lambda$, observed as a function of position, $z$, provides a direct measure of temperature within the hot zone of the extruder, analogous to a miniature optical fibre draw tower furnace. To characterise $\Delta\lambda$ in real-time and obtain the temperature, $T$, through the thermo-optic coefficient of the silica fibre, a Micron Optics Interrogator (SM130) is used.

## 3. RESULTS

Figures 1, 2 and 3 summarise the measured data and align that with the schematic of each extruder for each printer. Of the three printers, the largest discrepancy between the measurements and the thermocouple is obtained with the Redback printer, the most expensive of the three printers and one designed around delta operation. To rule out differences arising with the method of scanning, consultation with the manufacturer, a local start-up, verified the discrepancy is real and has since been rectified, demonstrating the practical value of the novel measurement process using FBGs. Overall, all three printers show very good distributions. Both the Redback and Flashforge show excellent agreement between dual nozzle heads. Despite being the lowest cost printer, the Flashforge has the smoothest distribution and the lowest temperature mismatch, although it does have a long secondary tail indicating thermal buildup as a result of fan overheating above the extruder head. The other printers are designed to avoid this problem with the Redback 2 probably being closest to an ideal top-hat profile. The Zortrax has an extended hot zone consistent with it longer body but it also shows a hot spot located where there is a junction between the metal extruder casing the material beyond this. This may suggest an air gap between the two materials, new information that is valuable to improving the engineering design of the printer.

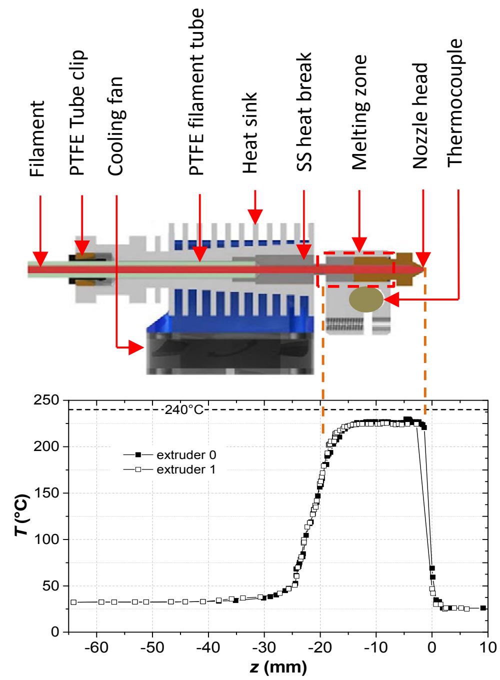


Figure 1. Temperature, $T$, profile along the printing nozzles of the Redback 2 printer as a function of position as measured by fibre Bragg grating (FBG). The nozzles are very well matched but reach a peak temperature less than $\Delta T \sim 13\ ^{o}C$ below that measured by the in-built thermocouple (240 $^{o}C$).

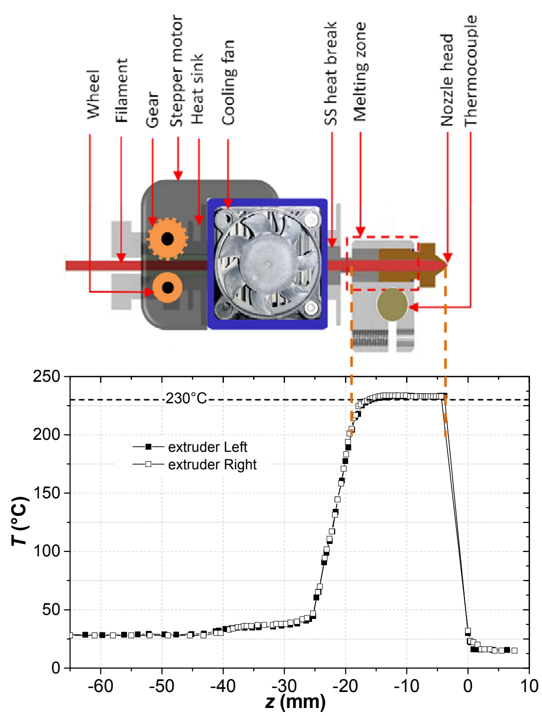


Figure 2. Temperature, $T$, profile along the two printing nozzles of the Flashforge Dreamer printer as a function of position as measured by fibre Bragg grating (FBG). The nozzles are very well matched and reach a peak slightly higher, $\Delta T \sim (3 - 5)\ ^{o}C$, above that measured by the in-built thermocouple (230 $^{o}C$).

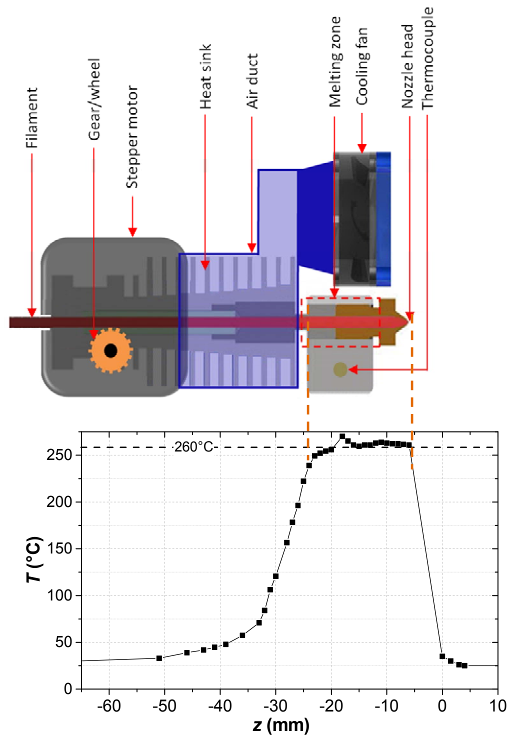


Figure 3. Temperature, $T$, profile along the two printing nozzles of the Zortrax M200 printer as a function of position as measured by fibre Bragg grating (FBG). The nozzles are very well matched and reach a peak slightly higher, $\Delta T \sim 1$ $^{o}$C, above that measured by the in-built thermocouple (260 $^{o}$C).

## 4. CONCLUSIONS

In conclusion, low cost desktop printers have been shown to have excellent micro-furnace extrusion heads, potentially suitable for not only 3D printing but for activities such as direct drawing of optical fibre and optical fibre tapers. Their temperature profile was characterised using high temperature performing fibre Bragg gratings of short length scanned with the 3D printer's own scanning technology. They make an excellent characterization tool for plotting the internal thermal distribution within the micro-furnace, not possible with an infrared gun – in principle it is possible to embed an array of high temperature gratings into the micro-furnace wall for permanent monitoring of the distribution over time. Given the relatively short lifetime of operation of current low-cost desktop printers, this could make an invaluable diagnostic tool to adjust their performance over time. The technology can also apply to much more expensive printers given the amount of time consuming and costly maintenance required to run customer outsourcing services.

## 5. ACKNOWLEDGMENTS

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