# 3D Printing Ribs, Fibres and Things

John Canning, Kevin Cook, Padraic Flanagan, Yanhua Luo, Gang-Ding Peng

*interdisciplinary Photonics Laboratories (iPL), Global Big Data Technologies Centre (GBDTC), TechLab, School of Electrical & Data Engineering, University of Technology Sydney (UTS)*

*& National Fibre Facility, Photonics & Optical Communications Group, University of NSW*
NSW 2007, 2019 & 2052 AUSTRALIA
john.canning@uts.edu.au

***Abstract*—Direct 3D printing of transmission and optical technologies such as optical fibres and waveguides is revolutionising research, enabling accessible and affordable capability to a much wider audience space. In this invited presentation we review the technology and its accessibility to everyone.**

***Keywords*— 3D printing, optical fibers, IoT, integrated optics**

## I. INTRODUCTION

3D printing has already been disruptive and is commonplace. High calibre printers are utilised in research and industry labs and workshops and centres [1], applied in areas as diverse as the medical and environmental space [2,3], technology and the arts [4]. These are the signatures of a technology integral to realising the internet-of-things (IoT), a transformational capability taking global communication networks away from communication to diagnostics of an unprecedented nature [5]. Enabling the functionality of the IoT and reducing key issues such as latency using photonics are optical fibres and waveguides. 3D printing is looking increasingly feasible as an approach to tackling these. In this presentation I will review proof of principle demonstrations that have made the vision realisable.

## II. PRINTING OPTICAL FIBRES AND WAVEGUIDES

The earliest work on directing light using 3D "printed "waveguides" had a focus on lighting up toys and props for children and theatre. It involved direct printing of short sections of polymer optical "fibre" [6] and "light pipes" [7]. A technical turning point of such technology was the use of this as an effective channel to guide light in an optical fibre endoscope smartphone configuration (the package itself 3D printed) [8]. This medically relevant application accompanied other 3D printed medically important photonic demonstrations including 3D printing of optical phantoms – objects used for the testing and evaluation of medical imaging devices [9]. 3D printed plastic micro lenses and customized ophthalmic lenses are now commercially available [10]. Polymer offers many advantages to optical sensing, especially combined with fibre Bragg gratings (FBGs) with large wavelength tunability for increased sensing dynamic range [11].

The turning point for telecommunications and the IoT was our articulation and demonstration of direct 3D printing of waveguides and thereby the IoT. The potential for revolutionizing optical fibre fabrication was also identified – imagine arbitrary design of preforms and fibres and waveguides of any sort [12] let alone functionalizing these and making components and so on. All merged with the growing transformation of packaging across industries already taking place, which in turn is accelerating the development of new very high technology startups and more. As proof of principle and bringing this vision to reality, polymer optical preforms were subsequently drawn into fibre [13,14], directly drawing fibres using the micro-furnace of a 3D printer [15] and planar rib structures [16] and 50:50 couplers [17], all useful in their own right as well as being precursors to silica-based technology. Whilst the quality of work has enormous scope for improvement, an interesting and important aspect was the demonstration of these firsts using some of the lowest cost printers on the market. This is a tribute to the fact that technology is becoming rapidly accessible to all! More importantly, the low-cost demonstrations using privately paid printers also predict a future where 3D printing will be low cost for much more advanced and lower loss versions to what has been demonstrated already.

To overcome resolution limits of the cheapest FDM printers (~ 200 to 400 μm at best) by using a novel overlap principle during writing, much narrower waveguides are possible for integrated optics [16]. This potentially competes with SLA/DLP technologies and expanding the accessible materials available for eventual single mode operation (though we note communications moving away from single mode to increasingly multi-mode technologies). Cut-back losses for structured polymer fibres were $\alpha$ ~ 1.5 dB/cm @ 632 nm, α ~ 0.75 dB/cm @ 1064 nm, and $\alpha$ ~ 1.51 dB/cm @ 1550 nm [18], whereas for a step index inner core fibre $\alpha$ ~ 0.64 dB/cm @ 543 nm, α ~ 0.44 dB/cm @ 1047-1052 nm and $\alpha$ ~ 0.94 dB/cm @ 1550 nm [13,14]. These match intrinsic material losses demonstrating the quality of material that is possible. Losses for the rib waveguides are generally much higher since there is no true guidance in the absence of a lower index substrate and the modes being leaky modes.

## III. PRINTING IN GLASS

3D printing of silica glass will be the next key target of interest because of its chemical resistance and high temperature performance and applications in long distance and low loss transmission systems for the IoT. For this field current technologies are not yet particularly low cost. We identify a number of promising approaches used for glass that may be suitable for fabricating a variety of silica-based 3D printed preforms and eventually optical fibres [18-20]. For example, early work in glass printing adopted an FDM approach using soda lime glass [18]; the printed structures were limited with a resolution of mm's and is not particularly practical in its current form for optical fibre and integrated optic applications – the approach by Flanagan *et al.* [16] can help address this). Other work used selective laser melting (SLM) with a $CO_2$ laser to print structures with soda lime glass [19] – the resolution is presently coarse and surface roughness high, but this can be improved. In 2017, printing high-purity, high resolution silica was demonstrated using SLA with a UV-curable monomer doped with silica nanoparticles. The printed part was initially opaque but after thermal debinding of the monomer and high-temperature sintering, a transparent silica object with spatial features of 10s of µm was reported [20]. Unfortunately, from an optical fibre perspective, these sintering based approaches where polymer or organic material is burnt off are not known to produce competitively low loss silica but may be enough for some application specific optical fibres.

## IV. CONCLUSIONS

With these ideas, proposals and preliminary demonstrations, a vision of a future of 3D printed IoT networks using 3D printed photonics, components, instruments and accelerated packaging technologies is being realised – these technologies span the entire IoT transmission ecosystem. Perhaps more importantly, is that much of these transformative technologies are increasingly within reach of the average global citizen.

## REFERENCES

[1] For example, Protospace at the University of Technology, Sydney Australia: https://www.uts.edu.au/partners-and-community/initiatives/city-campus-master-plan/campus-development-news/2017-news-6

[2] M. Mason, M. J. Golzan and J. Canning, “Smartphone Fundus Camera”, (Grad. School of Health), Capstone, UTS Australia, 2018.

[3] www.aussisystems.com.au

[4] H. Lipson and M. Kurman, Fabricated: the New World of 3D printing, John Wiley & Sons, 2013.

[5] J. Canning, “Smart Sensing & Photonics”, Conf. Lasers & ElectroOptics Pacific Rim (CLEO), Singapore, 2017.

[6] T Pereira, S Rusinkiewicz and W Matusik, “Computational light light routing: 3D pritning of optical fibres for sensing and display”, ACM Transactions on Graphics (TOG) TOG Homepage archive, vol. 33, 3, Article No. 24, 2014.

[7] K. Willis, E. Brockmeyer, S. Hudons and I. Poupyrev, “Printed optics: 3D printing of embedded optical elements for interactive devices“ UIST '12 Proc. 25th Ann. ACM Symp. User Interface Software & T, 2012, pp. 589-598.

[8] M. A. Hossain, J. Canning, K. Cook and A. Jamalipour, “Optical Fibre Smartphone Spectrometer”, Opt. Lett., vol. 41 (10), 2016, p. 2237.

[9] Phuong Diep, Sanjana Pannem, Jordan Sweer, Justine Lo, Michael Snyder, Gabriella Stueber, Yanyu Zhao, Syeda Tabassum, Raeef Istfan, Junjie Wu, Shyamsunder Erramilli, and Darren Roblyer “3-D printed optical phantoms with customized absorption and scattering properties”, Biomed. Opt. Express. vol. 6 (11), 2015, p. 4412.

[10] www.luxexcel.com

[11] Z. Xiong, G. D. Peng, B. Wu, “Highly tuneable gratings in single mode polymer fibre”, *IEEE Photonics Technology Letters*, vol. 11 (3), 1999, p. 352.

[12] J. Canning, *Structured Optical Fibres and the Application of their Linear and Non-Linear Properties*, in Selected Topics in Metamaterials and Photonic Crystals (Ed. Antonello Andreone, Andrea Cusano, Antonello Cutolo, Vincenzo Galdi, University of Sannio, Italy), World Scientific, 2011, ISBN 978-981-4355-18-6

[13] K. Cook, J. Canning, S. Leon-Saval, Z. Redi, Md. Hossain, J-E. Comatti, Y. Luo and G-D. Peng, “Air-structured optical fibre drawn from a 3D-printed optical preform”, Opt. Lett. Vol. 40 (17), 2015, p. 3966.

[14] K. Cook, G. Balle, J. Canning, L. Chartier, T. Athanze, M.A. Hossain, C. Han, J-E. Comatti, Y. Luo and G-D. Peng, “Step-index optical fibre drawn from 3D printed preforms”, Opt. Lett., vol. 41 (19), 2016, pp. 4554-4557.

[15] J. Canning, M. A. Hossain, C. Han, L. Chartier, K. Cook, and T. Athanaze, “Drawing optical fibres from 3D printers”, Opt. Lett., vol. 41 (23), 2016, pp. 5551-5554.

[16] P. Flanagan, K. Cook, J. Canning “3D Printed Photonic Ribs: a new platform for devices, sensors and more”, Asia Pacific Optical Sensors (APOS2018), Matsue City, Shimane, Japan (2018).

[17] K. Cook, J. Canning, “3D printed photonics”, Asia Pacific Opt. Sensors (APOS2018), Shimane, Japan (2018).

[18] S.S. Crump, US Patent 5121329 A, (1992).

[19] J. Klein, M. Stern, G. Franchin, M. Kayser, C. Inamura, S. Dave, J. C. Weaver, P. Houk, P. Colombo, M. Yang, and N. Oxman, “Additive Manufacturing of Optically Transparent Glass”, 3D Printing & Additive Man., vol. 2 (3), 2015.

[20] E.D. Dickens, US Patent 5990268 A, (1999).