Integration of Silicon Core Fibres to Single Mode Fibres using Nanospike with Improved Coupling Efficiency

H. Ren[1], O. Aktas[1], A. F. J. Runge[1], T. Hawkins[2], J. Ballato[2], U. Gibson[3], and A. C. Peacock[1]

1. Optoelectronic Research Centre, University of Southampton, SO17 1BJ, UK
2. COMSET, School of Materials Science and Engineering, Clemson University, Clemson, South Carolina 29634, USA
3. Department of Physics, Norwegian University of Science and Technology, 7491 Trondheim, Norway
E-mail: hr1g15@soton.ac.uk

Abstract: We integrate small core tapered polysilicon core fibres with standard single mode fibres via a Nanospike for efficient coupling. Both optical characterization experiment and simulation are investigated. This work provides a practical way for semiconductor fibre integration with conventional fibre system.

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1. Introduction

Silicon is a flexible semiconductor material that has attracted significant interest for photonics in recent times. By exploiting the advanced microelectronics fabrication techniques, chip-based silicon photonic devices with various functions have been demonstrated [1]. However, these planar-based devices are difficult to integrate with optical fibre systems favoured for communications applications. Thus, in the past decade, an alternative platform has emerged in which the silicon is incorporated directly into the fibre core [2]. Although these structures offer many of the advantages of standard glass fibres, the high refractive index of the silicon core still results in a significant mode mismatch and reflection which makes efficient light coupling difficult. To overcome this problem, different solutions have been suggested including microstructured fibres designed to improve the mode matching and chemical etching to reduce the end face reflection [2, 3], but these methods are complex and have demonstrated little improvement. A more effective solution that has been applied to both high index planar and fibre waveguides is to use an inverse taper structure at the coupling end face [4, 5]. The idea behind the inverse taper coupling is to match the mode index and mode area at the fibre output with SMF fibre. Decreasing the core size makes the mode leak out of the core. As a result, the mode index decreases and mode area expands. The single mode fibre is tapered small enough to transfer the core mode into a cladding mode. The coupling loss would be strongly reduced if the modes supported by the two different fibres are matching. This novel method greatly reduces the reflection loss and improves the mode matching dramatically.

In this paper, we demonstrate the simulation, fabrication and optical transmission of the inverse nanotaper silicon core fibre device integrated with a tapered single-mode fibre.

2. Fabrication

The silicon fibre was first fabricated via the molten core drawing technique [6]. To fabricate the nanospike the fibre was directly tapered using a Vytran GPX-3400 glass processing system. By applying additional heat to target a large tapering ratio, the Si core breaks up at the end of the down transition, as shown in Fig. 1a). The Si fibre can then be cleaved near the break-up point and spliced to an adiabatically tapered SMF28 fibre with a same outer diameter, as shown in Fig. 1b). To prevent the spike structure from melting, the splicing point is offset from the tip.

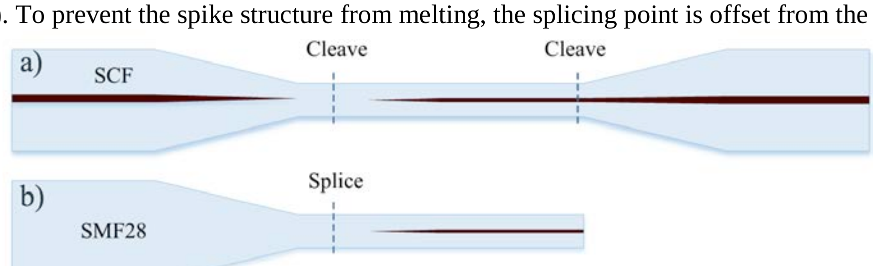

Fig. 1. Schematic of device fabrication. (a) Tapered Si core fibre with intentionally made core breakup. (b) Integration of the nanospike device with adiabatically tapered single mode fibre via splicing.

The nanospike decreases from the 2μm Si core down to a sub-micron scale with a smooth transition, as shown in Fig. 2a). To cleave the fibres with a few micrometres in diameter, a blade is installed manually on the Vytran splicehead. By applying a small tension on the fibre and raising the splicehead, the fibre can be cleaved precisely with good surface quality, as shown in Fig. 2b). Then we use the same Vytran system with small initial gap and slow hot push velocity to splice these fibres. In this work, we demonstrate cleaving and splicing fibre with a minimum diameter of 30μm, which is far below the commercial splicer limit.

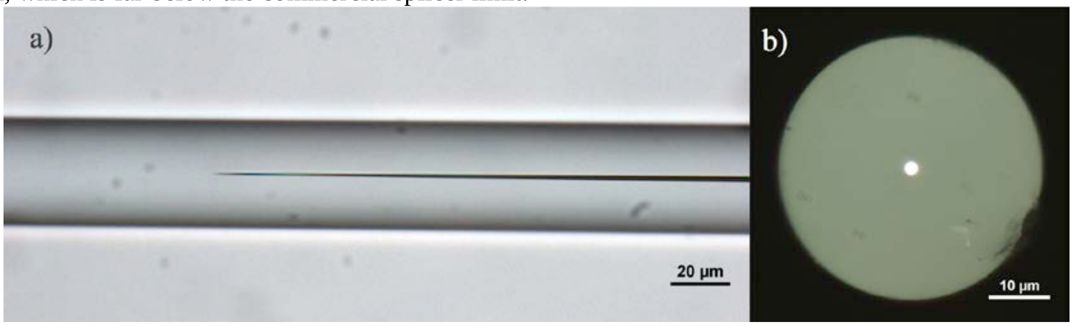

Fig. 2. Optical microscope image of (a) the Si nanospike, and (b) cleaved end facet of the nanospike device output.

3. Simulations and Optical Characterization

Since the nanospike is not perfectly adiabatic, we use COMSOL Multiphysics software to investigate the relations between the coupling efficiencies and the nanospike dimensions. Fig. 3a) shows the coupling efficiencies with different spike lengths and cladding diameters. It shows that decreasing the cladding diameter and increasing the tip length can greatly reduce the coupling loss. To characterize the device, we use a 1550 nm CW laser and an X63 microscope objective lens to collect the light at the output, as shown in Fig. 3b). The output mode is a mixture of the core and cladding modes. A pinhole is used to filter the cladding mode. The overall loss measured after the pinhole is 13dB, which includes connector loss of the laser, splicing loss, nanospike loss, propagation loss over 5mm, end face reflection loss and output coupling loss. The spike loss is estimated to be around 7dB which is competitive compared with free space coupling.

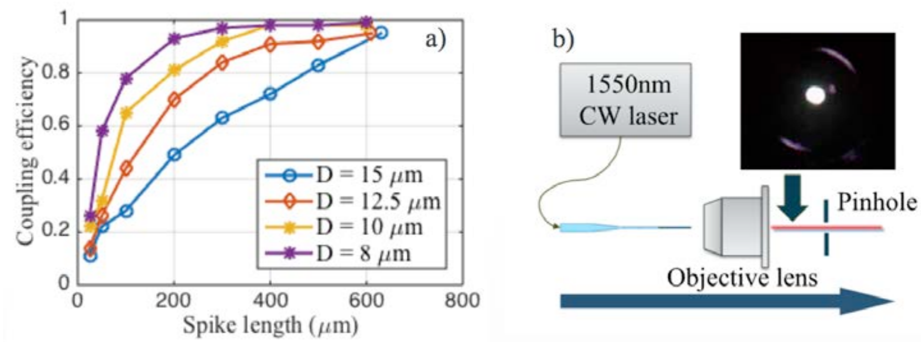

Fig. 3. (a) Simulation of device coupling efficiency versus spike length for different cladding diameters. (b) Optical transmission measurement setup. The inset shows the output mode from the Si core.

5. Conclusion

The nanospike splicing structure we developed successfully integrates small core silicon fibres with conventional single mode fibre with relatively low loss. Numerical modelling indicates that further optimization of the device can achieve ultralow loss coupling. This work provides a practical method for integrating semiconductor fibres with conventional fibre systems with efficient coupling and paves the way for fully integrated silicon fibre systems.

6. References

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