Nanowiring Light

Geoff T. Svacha and Eric Mazur
Department of Physics and Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA
mazur@physics.harvard.edu

Limin Tong
Center for Optical and Electromagnetic Research, State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou 310027, China phytong@zju.edu.cn

Abstract: Recent advances in the fabrication and manipulation of sub-wavelength optical fibers provide new methods for building chemical and biological sensors, generating supercontinuum light by nonlinear pulse propagation, and constructing microphotonic components and devices.
OCIS codes: (060.2400) Fiber properties; (220.4610) Optical fabrication

1. Introduction

We examine the properties of sub-wavelength dimension optical fibers as waveguides [1,2]. The silica sub-micrometer- or nanometer-diameter wires (SMNWs) reported here are suitable for low-loss optical wave guiding, and are promising components in future microphotonic devices for various applications, such as optical communications and optical sensing. Owing to their excellent uniformity, large length, high flexibility, and strength, these wires can be manipulated and assembled with high accuracy and used as micro- or nanoscale tools in physical, chemical, biological, microelectronic and materials research.

2. Fabrication and Manipulation

The SMNWs are fabricated using a two-step pulling process [1]. Standard single mode fiber is first pulled to a diameter of 2-5 μm over a flame. This micrometer-sized wire is then wrapped around a sapphire taper with diameter at the tip of ~80 μm. The sapphire tip is placed just inside the flame edge while the wrapped wire remains outside of the flame. The fiber is then pulled to sub-micrometer dimensions by applying tension perpendicular to the axis of the sapphire taper. The uniformity of the heat transfer through the sapphire taper avoids the turbulence that results from placing the fiber directly in the flame and allows us to produce SMNWs as small as 50 nm in diameter with lengths up to tens of millimeters.

The SMNWs can be manipulated with high precision under an optical microscope to produce bends as small as 5 μm, variable overlapping regions, as well as loops and knots. By bending them to the point of fracture, we find that the tensile strength of the wires is typically higher than 5.5 GPa [1]. When placed on a substrate, such as sapphire or silicon wafer, the Van der Waals attraction between the SMNW and the surface holds sharp bends and structures tightly in place.

3. Optical Properties

The pulling process yields wires with typical sidewall root-mean-square roughness less than 0.5 nm. This high uniformity allows these fibers to act as efficient waveguides [2]. We study the optical properties of the silica SMNW by using evanescent coupling. Light coupled into the single-mode fiber is transferred from one taper to another which is mechanically held to the first taper by the van der Waals attraction. We determined the optical loss of the SMNWs by measuring their transmission as a function of the length between the coupling region and taper. Typical loss values for 633 nm light on a 400 nm diameter SMNW are lower than 0.1dB mm^{-1} [1]. We find an increasing loss with decreasing wire diameter; this loss can be attributed to surface contamination: as the wire diameter is reduced below the wavelength, more light is guided outside the wire as an evanescent wave and becomes susceptible to scattering by surface contamination.

Because of the large index contrast between silica and air, silica SMNWs can be bent sharply without incurring large bending losses [2]. The ability to guide light through sharp bends is especially useful for miniaturization of photonic devices. For smaller diameters, more light propagates outside the silica core as an evanescent wave. Evanescent wave propagation is extremely useful for enhancing the performance of devices such as optical sensors. Smaller-diameter fibers also confine the mode diameter of the light thereby boosting the nonlinear effects that occur when short pulses are sent along the SMNWs.

4. References

1. Tong, L. M. *et al.* "Subwavelength-diameter silica wires for low-loss optical wave guiding." *Nature* **426**, 816-819 (2003)
2. Tong, L. M. *et al.* "Single-mode guiding properties of subwavelength-diameter silica and silicon wire waveguides." *Optics Express*, **12**, 1025-1035 (2004)

5. Acknowledgements

This work was supported by the National Science Foundation and by the National Natural Science Foundation in China. We also acknowledge the Center for Imaging and Mesoscale Structures at Harvard University. For further information, visit http://mazur-www.harvard.edu.