Low Bend Loss Femtosecond Written Waveguides Exploiting Microcrack Enhanced Modal Confinement

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While recent advances in femtosecond writing have allowed rapid and flexible realization of lab-on-chip and integrated optics systems in various media, miniaturisation of such fs-written waveguide architectures remains hampered by high bend loss α_b. Despite efforts to reduce bend loss, e.g. by annealing the waveguides [1] or writing stress structures [2], the minimum bend radius at telecommunications wavelengths remains > 16mm in silica [1]. To overcome this, we demonstrate a novel bend loss reduction method by inducing stress to fabricate a microcrack on the outer bend edge of the waveguide. The large index difference at the core-microcrack interface (1.45 vs 1.0) enhances modal confinement and inhibits radiation loss. Laser induced stress cracking is often used for dicing glass sheets with excellent smoothness (roughness < 30nm) [3]; hence such cracks will not exacerbate scattering.

We first simulated the bend loss of a curved buried waveguide in silica with and without the crack, modelled as a 50nm wide air gap on the outer bend edge of the core, using a finite element method technique (COMSOL). As an example, Fig. 1(a) shows the the intensity profile for a $10 \times 10\mu$m square step-index core ($\Delta n = 3.5 \times 10^{-3}$) with bend radius $R_b = 8$mm. Without the crack, the mode is lossy ($\alpha_b = 14$ dB/cm), whereas with the crack, the mode is indeed better guided with $\alpha_b = 2.1$dB/cm which confirms the feasibility of our approach.

Next, we wrote 90° waveguide bends of radii between $R_b = 3$ to 15mm in silica, using 200fs circularly polarised pulses at a wavelength of $\lambda = 515$nm generated as the second harmonic from a 200kHz 1030 nm Yb:KGW laser pump (PHAROS, Light Conversion). The beam was focused by a 0.4 NA objective onto the silica substrate positioned by computer controlled XYZ stages (Aerotech). All waveguides had $10\times10\mu$m cross sections written via the multiscan method [4] with 50 scanlines per waveguide. Each scanline was written at a high pulse density of 3×10^5 pulses/mm and pulse energy 55nJ. These parameters induce very high stress which is released in the form of a crack along the length of the waveguide during subsequent end facet polishing. Importantly, by writing the scanlines on the inner bend side first, the resulting stress asymmetry ensures that the crack consistently appears on the outer bend side of the waveguide as in Fig. 1(b). All waveguides were single moded with $1/e^2$ mode field diameters of $\approx$10μm and 9μm at $\lambda = 1550$ and 1310nm, respectively.

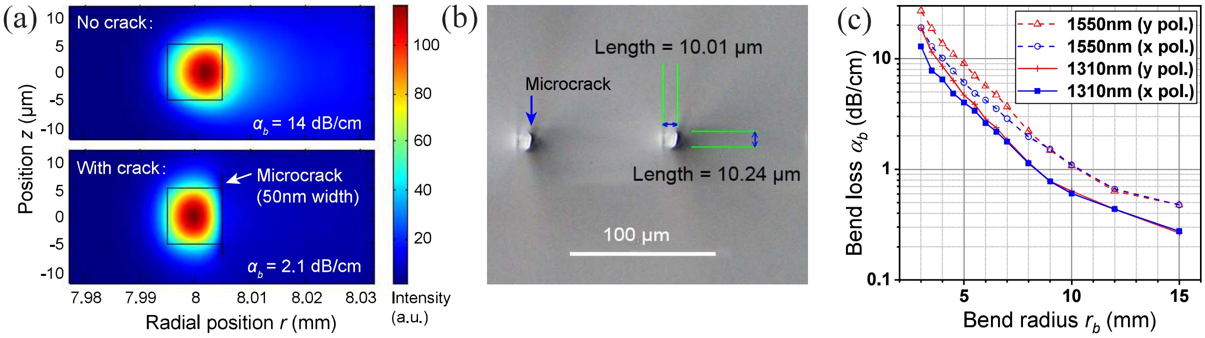

Fig. 1. (a) Simulated x-polarised fundamental mode intensity profile at λ =1550nm for a silica waveguide of 8mm bend radius without and with crack. (b) Microscope image of waveguide output facets, showing cracks on the right edge of waveguides, i.e. on outer side of the bend. Left edge of cores are uncracked. (c) Experimentally measured bend losses for x and y polarisations at λ =1550nm and 1310nm.

The measured bend losses given in Fig. 1(c) shows excellent guidance even for bend radii well below 10mm. For $\lambda = 1550$nm and 1310nm, the loss reaches 3dB/cm at $R_b = 6$mm and 7mm, respectively, which is a significant improvement on previously published works [1,2]. Moreover, the loss for the x and y polarisations are similar, with negligible polarisation dependent loss (PDL) when $R_b > 8$mm. The PDL does however increase as bend radius becomes tighter because the x-polarised mode is better guided, as confirmed by simulations.

The microcrack is a straightforward solution to reduce bend loss, implemented during the femtosecond inscription process itself without the need for postprocessing other than polishing. Since it does not modify the volume around the waveguide, it can be flexibly incorporated into complex designs with closely spaced waveguides.

References

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