losses appearing in our experimental results for both fibers - conventional and hybrid - are usually linked to the coupling between core and cladding "leaky" modes. This oscillatory character of losses versus bending diameter has been extensively investigated in [18,19].

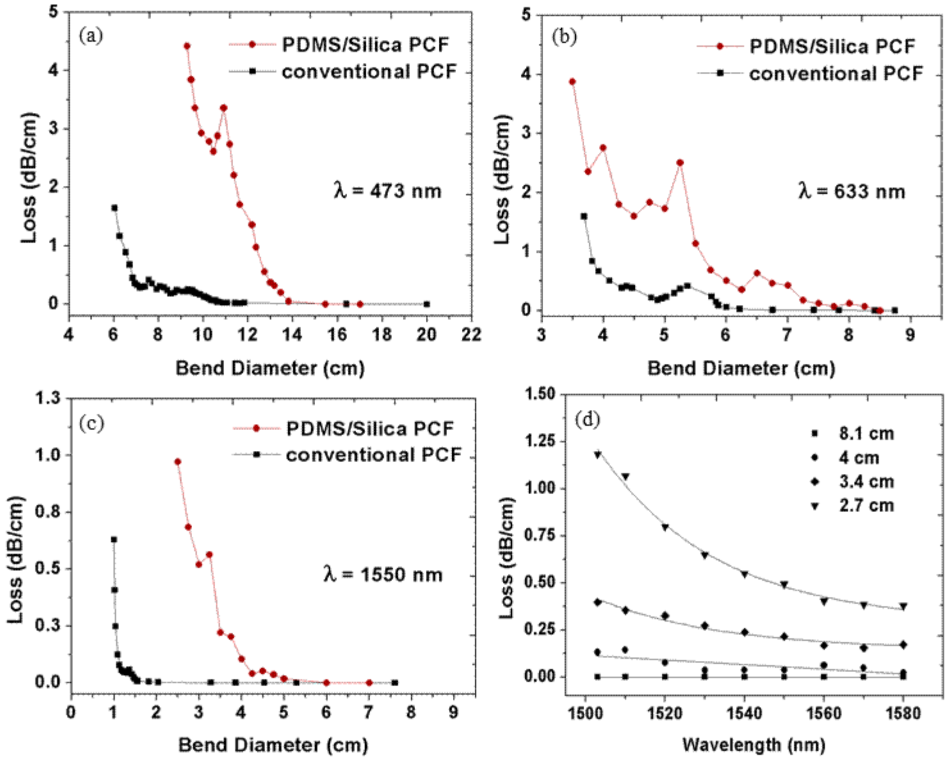

Fig. 3. Bending loss as a function of bend diameter at (a) 473, (b) 633 and (c) 1550 nm wavelength for a conventional and PDMS/silica PCF. (d) Measurement of bend loss variation as a function of wavelength for the case of hybrid PDMS/silica PCF at different bend diameters.

The wavelength dependence of the bending properties was also examined using a tunable C-band laser source at four different bending diameters. Figure 3(d) shows strong wavelength dependence for small bending diameters and short wavelengths and a relative weak (almost flat) dependence for large bending diameters and wavelengths ranged higher than 8.1 cm and 1570 nm, respectively. It is worth noting here, that the conventional ESM-PCF exhibited negligible bend loss for such bend diameters.

3.3 Thermo-optic effect

Normally, the temperature dependence of the refractive index is described by the thermo-optic coefficient d*n*/d*T*, which quantifies the shift of the refractive index arising from an infinitesimal change of the temperature. The PDMS elastomer, among the others optical properties mentioned previously, also exhibits a highly linear, negative thermo-optic coefficient corresponding to $dn/dT = -4.5x10^{-4}/\ °C$ [20]. Based on this change of refractive index with temperature, we calculated the corresponding effective indices of the fundamental guiding mode of the hybrid PDMS/silica PCF for different temperatures. Figure 4(a) and 4(b) show the effective index difference (Δn_{eff}) of each effective index calculated from 25 - 75°C, from the initial one calculated at room temperature (20°C) for the wavelengths of 633 and 1550 nm, respectively.. Δn_{eff} is almost an order of magnitude higher at 1550 nm, due to the low mode confinement and the large overlap between the guiding mode and cladding.

Figure 4(c) shows the effective modal area of the hybrid PCF for the same range of temperatures at 633 and 1550 nm.

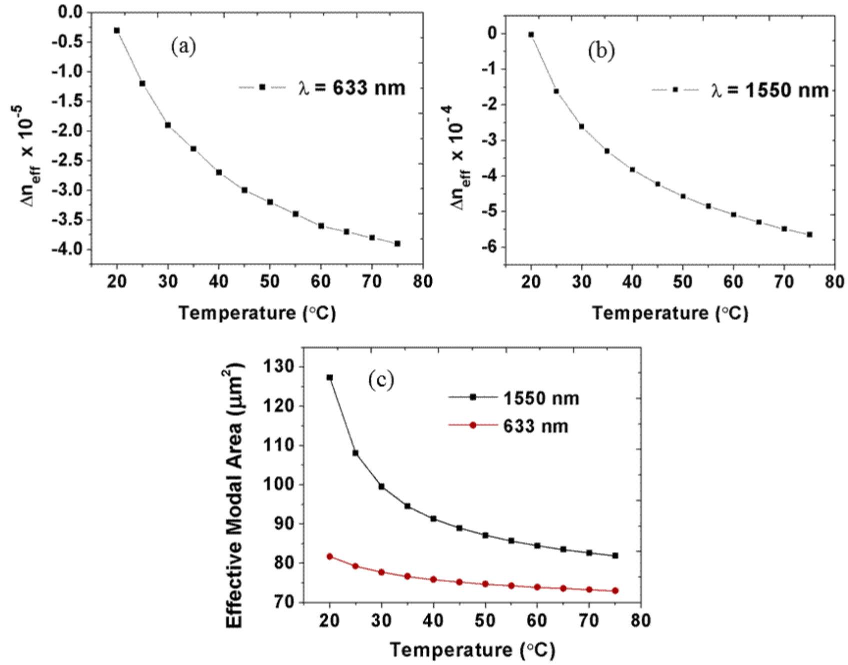

Fig. 4. Index difference variation, Δn_{eff} of PDMS/silica PCF as a function of temperature at (a) 633 nm and (b) 1550 nm operating wavelength. (c) Effective modal areas at 633 and 1550 nm wavelength.

Increasing the temperature, the refractive index contrast between cladding and core also increases, allowing for the fundamental guiding mode to be partially reconstructed back to the core of the fiber. FDTD analysis was performed for a temperature range of 20°C -to- 75°C and for a bend diameter of 4 cm. In Fig. 5, we present the electric field distribution (logarithmic scale) of the fundamental mode for a set of frames per 10°C from the simulation videos at 633 nm (see a - f) and 1550 nm (see g - l). In both cases the mode of the bent fiber is asymmetric in shape and shifts towards the outside of the bend near room temperature. As the temperature increases, the guiding mode starts accumulating at the core. At 633 nm the thermo-optic effect cannot overcome the high bend loss and the partial recovery of the fundamental mode is limited compared to 1550 nm.

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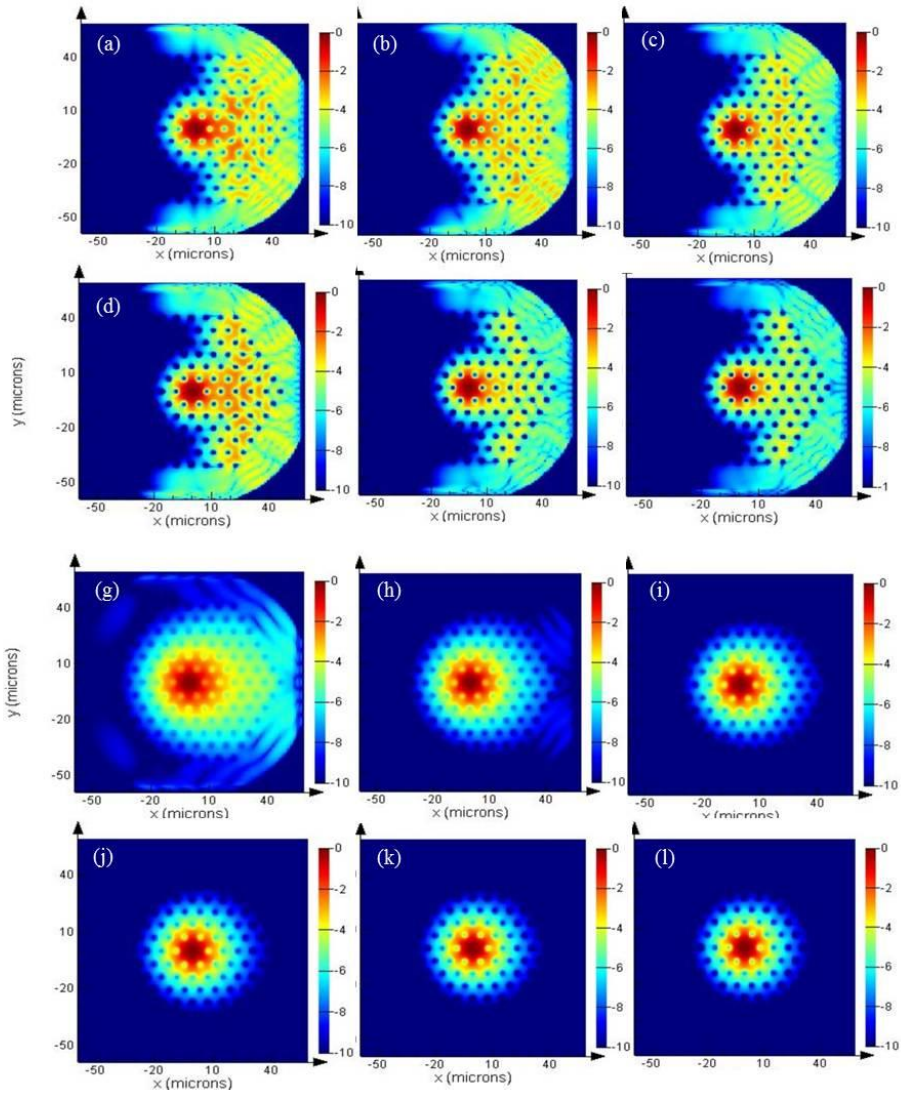

Fig. 5. Single-frame(one per 10°C) excerpts from two separate simulation videos illustrating the partial reconstruction of the fundamental guiding mode of the hybrid PDMS/silica PCF as temperature increases from 20°C to 75°C for a bend diameter of 4 cm. Frames (a-f) correspond to 633 (Media 1) and (g-l) to 1550 nm wavelength (Media 2) (logarithmic scale).

The thermo-optic sensitivity of the hybrid PCF, induced by the elastomer inclusion, was also investigated experimentally. We placed the hybrid PCF at a bend diameter of 4 cm on top of a peltier element with perfect thermal contact to the surface. Using a laser source, a power meter, and a thermo-couple we measured the amount of power recovered from the bending induced loss. Figure 6(a) shows how bending loss varies with the increase of temperature at 633 nm and clearly shows a recovery of ~3.6% of the total transmitted power, at 75°C. Same measurements were repeated at 1550nm, investigating the thermo-optic sensitivity at longer wavelengths and the bend-induced power loss recovery corresponded to 5.93%. Results are shown in Fig. 6(b). Slight discrepancies appeared in our experimental results derived from a combination of losses arising in the fabrication process and experimental characterization of the device (absorption due to impurities, scattering, human error, etc.). The temperature sensitivity was defined as ΔPower/ΔTemp and estimated to be 0.05 dB/°C at 633 nm and 0.005 dB/°C at 1550 nm. In the case of the conventional ESM-PCF, power was unrecoverable

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either at 633nm or 1550 nm wavelength due to very small thermo-optic coefficient of fused silica [21].

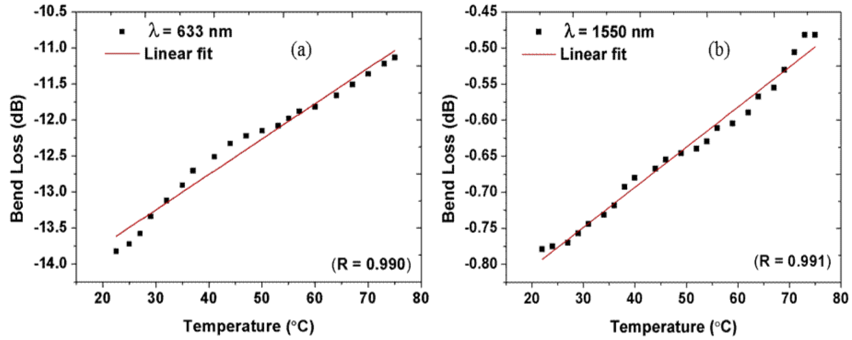

Fig. 6. Thermo-optic effect of PDMS-filled PCF for a bend diameter of 4 cm at (a) 633 and (b) 1550 nm.

4. Conclusion

In conclusion, we have demonstrated for the first time towards our knowledge, a hybrid PDMS/silica PCF. We examined the guiding mechanism of the hybrid fiber, where acceptable level of loss measured over short lengths. Bend measurements of the PDMS/silica PCF at different wavelengths were carried out, demonstrating the dramatic shift of the short and long bend loss edge to higher bend diameters compared to a conventional PCF. Further numerical calculations indicated the dependence of the effective index of the fundamental guiding mode of PDMS/silica PCF with temperature and we demonstrated how the fundamental mode of a bent fiber can be reconstructed due to thermo-optic effect of the PDMS inclusions. It was also experimentally shown that there was a ~6% bend-induced power loss recovery at a range of temperatures up to 75°C. The hybrid PDMS/silica PCF has the potential to be used for macro-bend sensing, whereas the feature of power recovery with temperature, further enhances the ability of the fiber to act as temperature-tuned device over a wide range of wavelengths. Finally, it is relatively simple to be developed using commercially available PCFs and a low cost elastomer material.

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