A finite element characterization of a commercial endlessly single-mode photonic crystal fiber: is it really single mode?

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One of interesting properties of photonic crystal fibers (PCFs) is their possibility to be single-moded over a wide wavelength range, down to UV, while still having a reasonably large modal profile. Such properties are attractive for applications like optical sensing, interferometry, and transport of white light. PCFs, which is designed specially for such property are known as the endlessly single-mode (ESM-) PCFs [1].

However, the ESM property requires the holey cladding of a PCF to have a small air-filling factor. Such a requirement indeed creates problems for PCF manufacturers, as it does not go in harmony with other equally important properties of the PCF. A small air filling factor implies large leakage loss. So, the characteristics of commercially available ESM-PCFs, in fact come out from compromises between the desirable endlessly-single-modeness and the low leakage loss properties. Hence, depending on the type of applications, the term ESM itself could mislead its users, if the endlessly single modeness is presumed without proper precautions.

In this work, using a vectorial finite-element leaky mode solver published recently [2], several dominant leaky modes of a commercial ESM-PCF [3] were investigated. Although the leakage loss of the fundamental mode is already 6 orders lower (on a dB/unit-length scale) than that of the nearest higher order modes, the leakage losses of these higher order modes are still quite low, which might still be significant, especially for short wavelength and short fiber-length applications. In addition to the ordinary-fiber-like hybrid core modes, the existence and significance of unusual modes like cladding-resonance modes and core-cladding-resonance modes were also numerically observed. Based on the loss discrimination between the most dominant and the nearest higher order mode, we set-up a criterion for the single-modeness. Using that measure, we verified the single-modeness of the corresponding ESM-PCF and found that the endlessly single-modeness is valid only for a relatively long fiber, typical of local area network applications. This finding implies that applications employing short fiber-length, working in short wavelength regimes, should be prepared for significant effects of the higher order modes, e.g. by employing a mode stripper to suppress their effects. We suggest that ESM-PCF for short fiber-length applications need to be designed differently from those for long fiber-length applications.

References

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