

Trondheim, September 11, 2019

The comments from the reviewer are repeated below in *italics*, followed by our response. In the responses the removed text is shown in red and the added text is shown in blue; all page numbers in our responses refer to the manuscript.

Response to reviewer 1

The manuscript is much improved at current version, so I recommend its publication in present format. Just one small typo I have noticed in the abstract, "Comparisons to experimental results indicates that" should be "Comparisons to experimental results indicate that".

Response: We appreciate the time and effort put in by the reviewer and the valuable comments and suggestion we have received. We have corrected the typo in the abstract.

Response to reviewer 2

1) It is not evident if the modal dispersion is considered to achieve the effective indices of optical modes. All discrepancy may be caused by the modal dispersion.

Response: We again thank the reviewer for taking the time to read our manuscript carefully and for offering valuable comments and suggestions. Our model considers chromatic dispersion of the individual modes, but we agree that the manuscript is unclear on how it is done. Group velocity dispersion of each mode is not included because of its small effect compared to the inter-modal interference. We have therefore made the following changes:

Page 3, line 116: (removed)

~~"The effective RIs are calculated at two wavelengths to account for material and waveguide dispersion. The mode fields also change with wavelength, but this effect is considered negligible as it mainly affects the result through a small and uniform difference in the excitation coefficients. In contrast, a small change in effective RI causes the phase difference to accumulate as the field propagates through the fiber."~~

Page 4, line 129: (inserted)

The effect of the angled end face is to produce a linear phase shift across the mode and a spatial displacement between incident and reflected mode. For small cleave angles the effect of the displacement is negligible. ~~This effect can be explored~~ Thus, the effect of the angled end face is modelled by propagating the initially excited set of modes to the cleaved interface, where the field becomes:

Page 4, line 134: (inserted)

z_0 is the original length of the fiber

Page 4, line 146: (inserted)

"To calculate the effective indices over the wavelength interval considered, the modes are calculated at two wavelengths to account for material [26] and waveguide dispersion. A linear approximation is employed to find the effective index for each mode as a function of wavelength. This approximation is considered valid as the derivative of the effective index with regards to wavelength is approximately constant [14]."

Page 4, line 151:

Because of the evanescent field present around the fiber, a change in the external RI will affect the effective RI of the modes. To incorporate this RI sensitivity in the model, the confinement

coefficients are calculated from the mode fields, as a function of wavelength. The effective RIs of the modes, as a function of external RI, are then estimated from a weighted average based on the confinement coefficients. The model does not, however, consider the decreased confinement of the modes caused by the lower index contrast at higher external RI. According to the study [14], this seems to be a reasonable ~~assumption~~ approximation. The mode fields used to calculate the excitation coefficients are the same for all wavelengths. Thus, the effect of mode field changes with wavelength, resulting in a small and uniform change in the excitation coefficients, are considered negligible. ~~This effect is estimated from a weighted average based on the confinement coefficient of each mode. A linear approximation to the material and waveguide dispersion is considered when calculating the effective RI. The mode fields are assumed to remain unchanged within the small range of RI considered.~~

Page 7, line 242:

“Compared to our experimental results, the simulation is valid only for RIs close to $n_{ext} = 1.33$, since the model does not consider the increased evanescent field at higher RIs. The model considered in this work is expected to underestimate the RI sensitivity as it assumes that the mode fields are independent of ~~wavelength~~ the external RI.”

2) *The cleaving angle vs. numerical aperture of modes regarding the mode order must be included in the manuscript in order to discuss the mode excitation at the angled end face.*

Response: We are not sure how to interpret “numerical aperture of modes regarding the mode order”. One interpretation we have found is that the numerical aperture of the fiber decides the diffraction angle of the modes when the system is treated within geometrical optics. The cleaving angle would alter the diffraction angle in the reflected field and could thereby affect the output spectrum. We would therefore like to explain our method further, to justify why we think our model adequately describes the effect of the cleave angle.

We consider the angled cleave to be conceptually equivalent to a tilted junction between two fibers. According to the book *Optical Waveguide Theory* by Snyder and Love (p. 430), the junction can be regarded as a beam incident on the second fiber at an angle. In our case the “wedge” between the two fibers is at most around one micron thick. The short propagation distance will by a first order approximation cause a lateral displacement of the field that is negligible compared to the transverse dimensions of the coreless fiber. Also, if this wedge is considered to allow free space propagation of the mode fields, the propagation length will be too short to allow for large changes in the field due to the divergence angle of the mode. This argument is supported by a comparison to the “Rayleigh range” of Hermite-Gaussian beams ($z_0 = \pi/\lambda W_0^2$), which is far larger than 1 μm for all waist radii ($W_0 > \lambda/\pi$). We therefore argue that we should be able to disregard any diffraction complicating the effect of the angled cleave. This same model has been widely used in the literature, e.g. by M. Han and A. Wang, “Exact analysis of low-finesse multimode fiber extrinsic Fabry-Perot interferometers,” *Appl. Opt.*, vol. 43, no. 24, pp. 4659–4666, 2004, and D. T. Neilson, “Tolerance of optical interconnections to misalignment,” *Appl. Opt.*, vol. 38, no. 11, p. 2282-2290, 1999.