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Scalable fabrication of twisted aperiodic multicore fibers for next-generation lens-less endoscopy

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Many biomedical applications require 3D imaging deep inside tissue. In this context, lens-less endoscopy, based on multicore fibers (MCFs), is a promising concept [1]. However, the cores in most conventional MCFs are arranged periodically. This periodicity causes artefacts during imaging in analogy to higher-order diffraction side lobes of periodic gratings. These in turn have a crucial impact on the performance, e.g. spatial resolution, of the endoscope. Such imaging artefacts can be reduced significantly by aperiodic core arrangements [2] but a scalable fabrication concept of such fibers is missing, so far. State-of-the-art aperiodic MCFs feature only insufficiently low core numbers of less than around 200. Furthermore, since lens-less endoscopy is sensitive to dynamic bending of the fiber, solutions like twisting [3] of the fiber must be incorporated into the fabrication. This enables correction of phase distortion by static DOEs produced by 2-Photon Polymerization on the fiber facet [4].

Our advanced and scalable fabrication approach is based on an iterative stack&draw approach as presented in [5]. However, we combined it with in-depth numerical studies in order to identify the ideal trade-off between sidelobe suppression, core density, and cross-talk. Simulations revealed that a randomized stacking of so-called subgroups with three off-centric cores is the most promising approach. With a core NA of around 0.3, two MCFs were fabricated so far: (i) a 250 µm fiber with 420 cores and (ii) a 333 µm fiber with 1281 cores, see Fig. 1 (a). The 1281 core fiber has a design core diameter of around 1.5 µm, which means the cores are theoretically single-mode for wavelengths larger than 470 nm, which was confirmed experimentally. Furthermore, to characterize the cross-talk in the fiber, experiments with a structured illumination of a 2 m long sample of the 1281 core fiber were performed. A rectangular 75 µm x 100 µm window of one fiber facet was illuminated by a standard microscope. Imaging of the other facet did not show any power leakage into surrounding cores, see Fig. 1 (b). In parallel to the fiber fabrication, two approaches were tested to twist the fibers: (i) rotation of the fiber preform during fiber drawing and (ii) post-production twisting of the MCF within a fiber processing station. While the first approach yielded a twist period of around 1 cm^{-1}, the second approach provided a period of up to 2.5 cm^{-1}, see Fig. 1 (c). Preliminary experiments regarding the cross-talk in the twisted fibers revealed that it is not substantially influenced by the twisting.

In our contribution, we will present a scalable fabrication method of aperiodic MCFs assisted by numerical optimization and the MCF characterization. In addition, we will discuss the mentioned experiments regarding twisting of the MCFs as well as the resulting imaging properties.

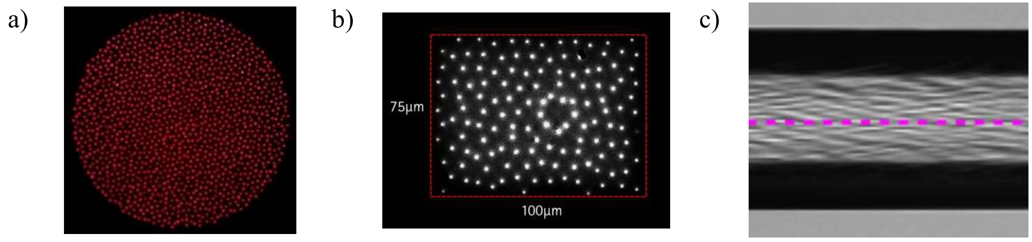

Fig. 1: *(a): The 1281 cores of the aperiodic multicore fiber (b): Structured illumination did not indicate any substantial cross-talk. (c): Side view of the twisted fiber with a twist period of 2.5* cm^{-1}.

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