



HAL
open science

Two-Photon Lensless Endoscopes with Multicore Fibers

Fatima El Moussawi, Matthias Hofer, Siddharth Sivankutty, Andrea Bertoncini, Damien Labat, Andy Cassez, Geraud Bouwmans, Rosa Cossart, Olivier Vanvincq, Carlo Liberale, et al.

► **To cite this version:**

Fatima El Moussawi, Matthias Hofer, Siddharth Sivankutty, Andrea Bertoncini, Damien Labat, et al.. Two-Photon Lensless Endoscopes with Multicore Fibers. 2023 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Jun 2023, Munich, France. 10.1109/CLEO/Europe-EQEC57999.2023.10231882 . hal-04282751

HAL Id: hal-04282751

<https://hal.science/hal-04282751>

Submitted on 14 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Two-photon lensless endoscopes with multicore fibers

Fatima El Moussawi¹, Matthias Hofer², Siddharth Sivankutty¹, Andrea Bertoncini³, Damien Labat¹, Andy Cassez¹, Geraud Bouwmans¹, Rosa Cossart⁴, Olivier Vanvincq¹, Carlo Liberale³, Herve Rigneault², Esben Ravn Andresen¹

1. Univ. Lille, CNRS, UMR 8523 - PhLAM - Physique des Lasers Atomes et Molécules, F-59000, Lille

2. Aix-Marseille University, CNRS, Centrale Marseille, Institut Fresnel, F-13013 Marseille, France

3. Computer, Electrical and Mathematical Sciences and Engineering Division, King Abdullah University of Science and Technology (KAUST), Saudi Arabia

4. Aix Marseille University, INSERM, INMED, Turing Center for Living Systems, F-13273 Marseille, France

The lensless endoscope represents the ultimate limit in miniaturization of imaging tools: an image can be transmitted by numerical or physical inversion of the mode scrambling process through a bare optical fiber. Lensless endoscopes featuring multicore fibers and spatial light modulators are well adapted for nonlinear imaging as they minimally distort ultrashort pulses in the time domain as opposed to multimode fibers [1]. And in earlier works, we had addressed the issues of imaging artifacts and bending sensitivity with an helically twisted multicore fiber with a sparse and aperiodic core layout in the transverse plane [2]. However sufficiently irradiating the sample plane remained a major challenge – particularly for the imaging of dim and challenging samples such as neurons in scattering media.

In this contribution, we outline the fundamental physics behind the origin of the low irradiance at the focal plane in MCF based endoscopes, and present here two novel approaches that addresses this issue. The first is an all fiber-optic component, a "tapered multi-core fiber (MCF)", designed for integration into ultra-miniaturized endoscopes for minimally invasive two-photon point-scanning imaging.[3] This new design addresses the power delivery issue that has faced MCF based lensless endoscopes. We achieve experimentally a factor 6.0 increase in two-photon signal yield while keeping the ability to point-scan by the memory effect, and a factor 8.9 sacrificing the memory effect. We report two-photon fluorescent imaging of cells and neurons with these improved MCF tapered fibers over a field of view of 100 microns.

And in a second approach, we use 2 photon direct laser writing to 3D print micro-optical components – namely a "hyper-telescope". on the tip of a multicore fiber.[4] This allows us to coherently combine 120 beamlets with an experimental efficiency of 0.35. This leads to about a 100 fold improvement in the two-photon signal over an unmodified MCF. These two major advancement in power delivery through MCFs opens the route towards the use of MCF based lensless endoscopy in challenging imaging conditions.

References

- [1] Andresen, E. R., Sivankutty, S., Tsvirkun, V., Bouwmans, G. and Rigneault, H., "Ultrathin endoscopes based on multicore fibers and adaptive optics: A status review and perspectives," *Journal of Biomedical Optics* 21(12) (2016).
- [2] Tsvirkun, V., Sivankutty, S., Baudelle, K., Habert, R., Bouwmans, G., Vanvincq, O., Andresen, E. R. and Rigneault, H., "Flexible lensless endoscope with a conformationally invariant multi-core fiber," *Optica* 6(9), 1185 (2019).
- [3] El Moussawi, F., Hofer, M., Labat, D., Cassez, A., Bouwmans, G., Sivankutty, S., Cossart, R., Vanvincq, O., Rigneault, H. and Andresen, E. R., "Tapered Multicore Fiber for Lensless Endoscopes," *ACS Photonics* 9(8), 2547–2554 (2022)..
- [4] Sivankutty, S., Bertoncini, A., Tsvirkun, V., Gajendra Kumar, N., Brévalle, G., Bouwmans, G., Andresen, E. R., Liberale, C. and Rigneault, H., "Miniature 120-beam coherent combiner with 3D-printed optics for multicore fiber-based endoscopy," *Opt. Lett.* 46(19), 4968 (2021).