

High-resolution reflectance endomicroscopic imaging free from back-reflection noise at ultrathin imaging probes

Changhyeong Yoon^{1,2}, Munkyu Kang^{1,2}, Jin H. Hong^{1,2}, Taeseok D. Yang⁴, Hongki Yoo³, Youngwoon Choi⁴, and Wonshik Choi^{1,2}

¹Center for Molecular Spectroscopy and Dynamics, Institute for Basic Science (IBS), Seoul, Korea

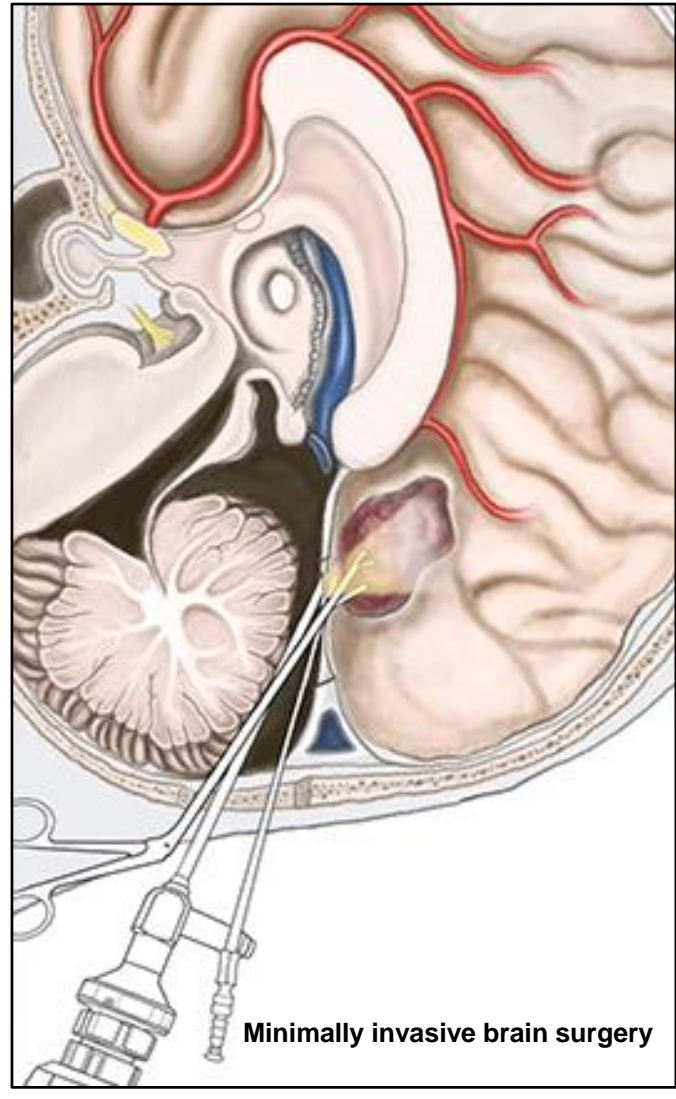
²Department of Physics, Korea University, Seoul, Korea

³Department of Bioengineering, Hanyang University, Seoul, Korea

⁴School of Biomedical Engineering, Korea University, Seoul, Korea

Introduction :

The necessity for microendoscope

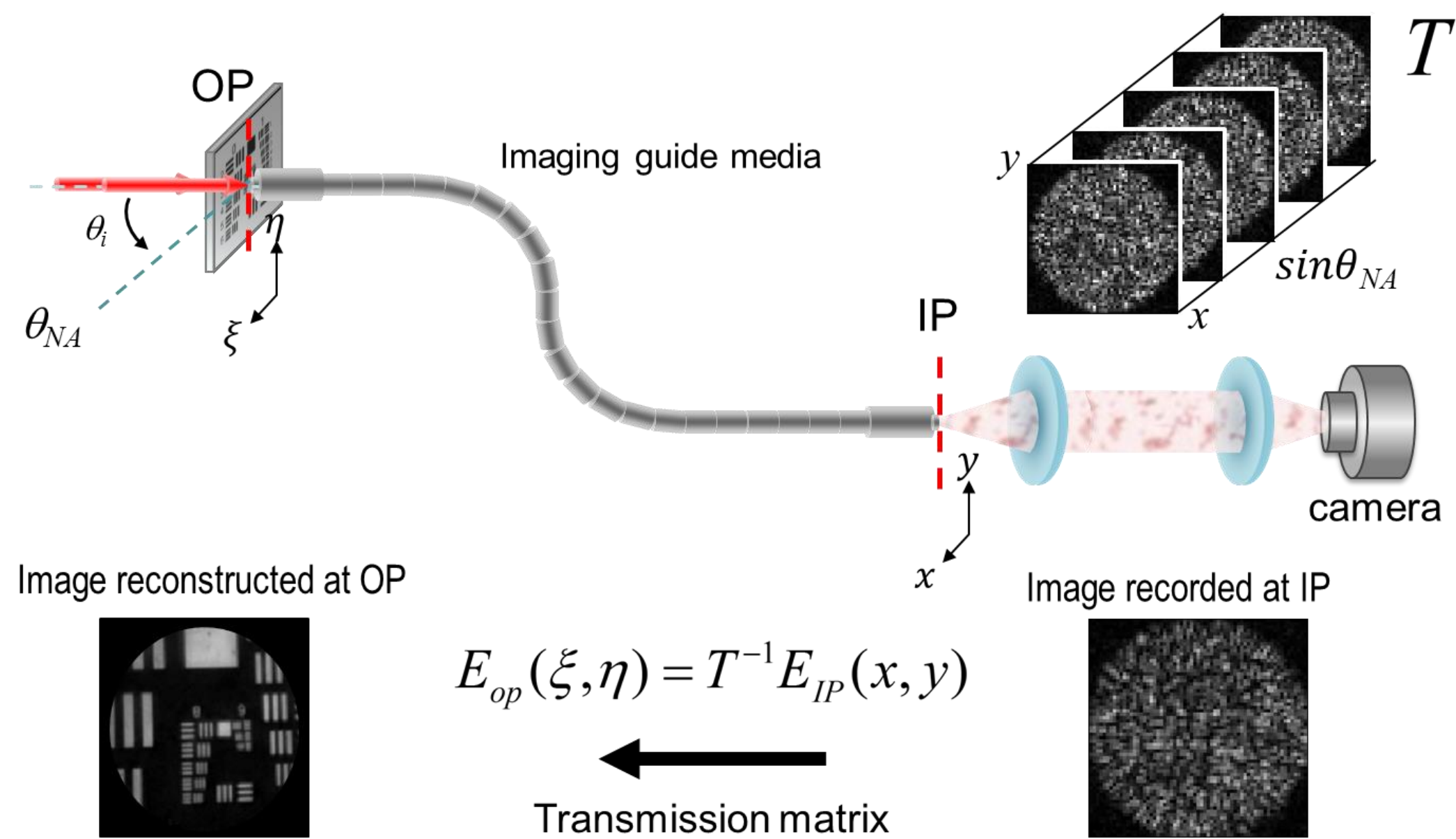


- It is possible to minimally invasive endoscopic imaging
- Microscopic level of spatial resolution

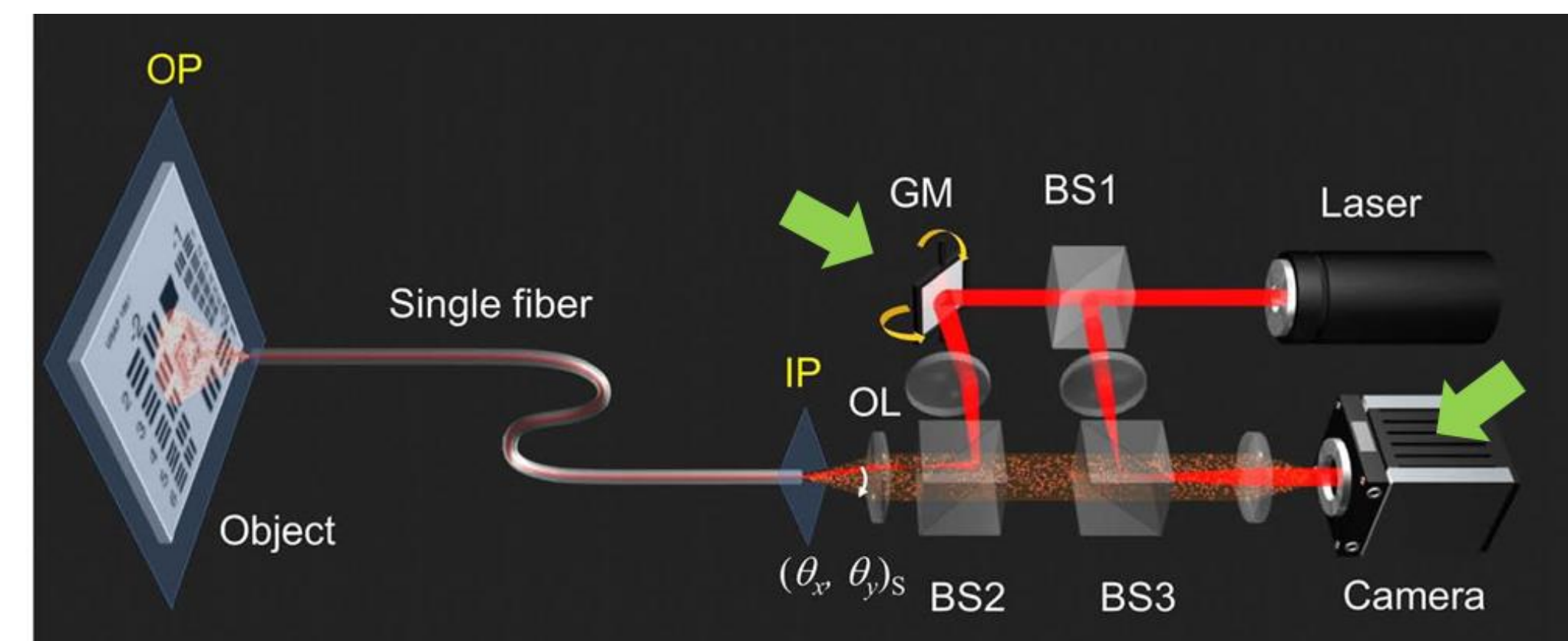
Previous work :

Lensless Single-Fiber Microendoscopy

Image reconstruction by transmission matrix

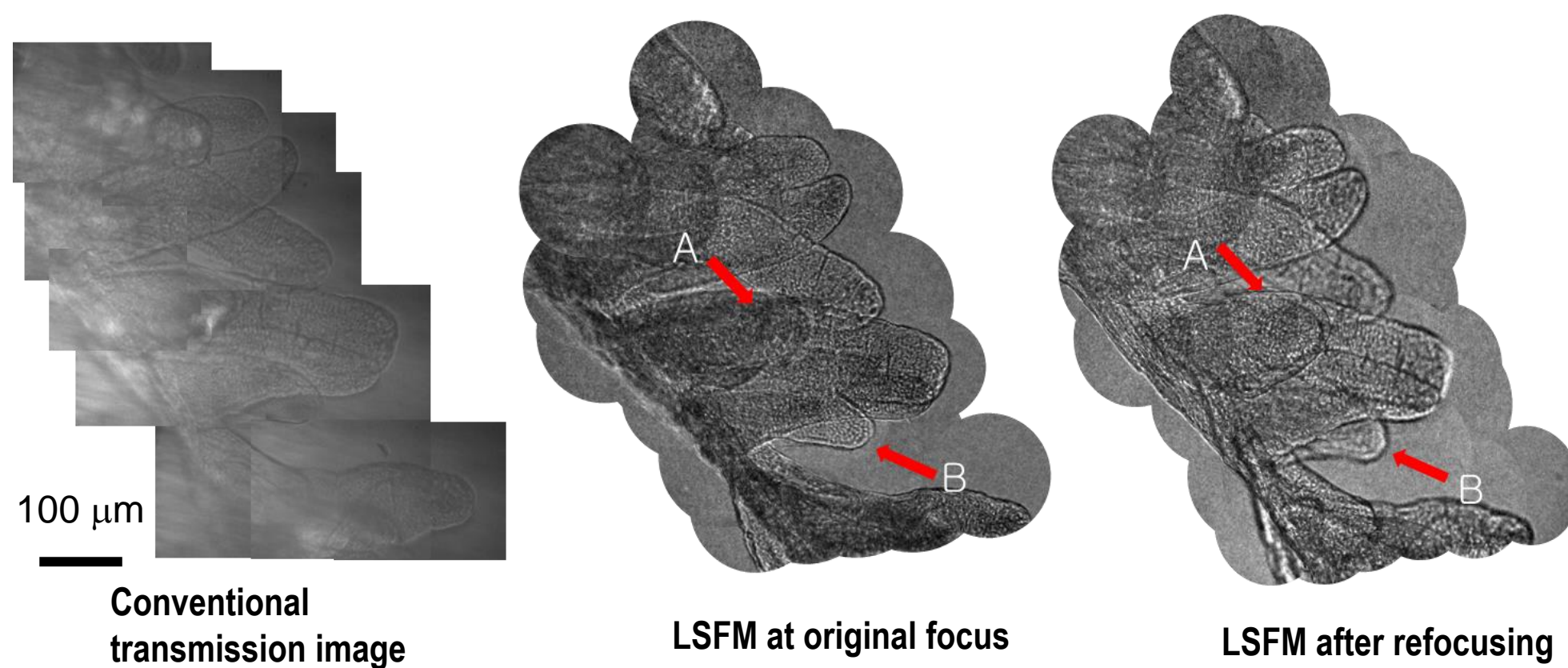


Lensless single-fiber microendoscopy



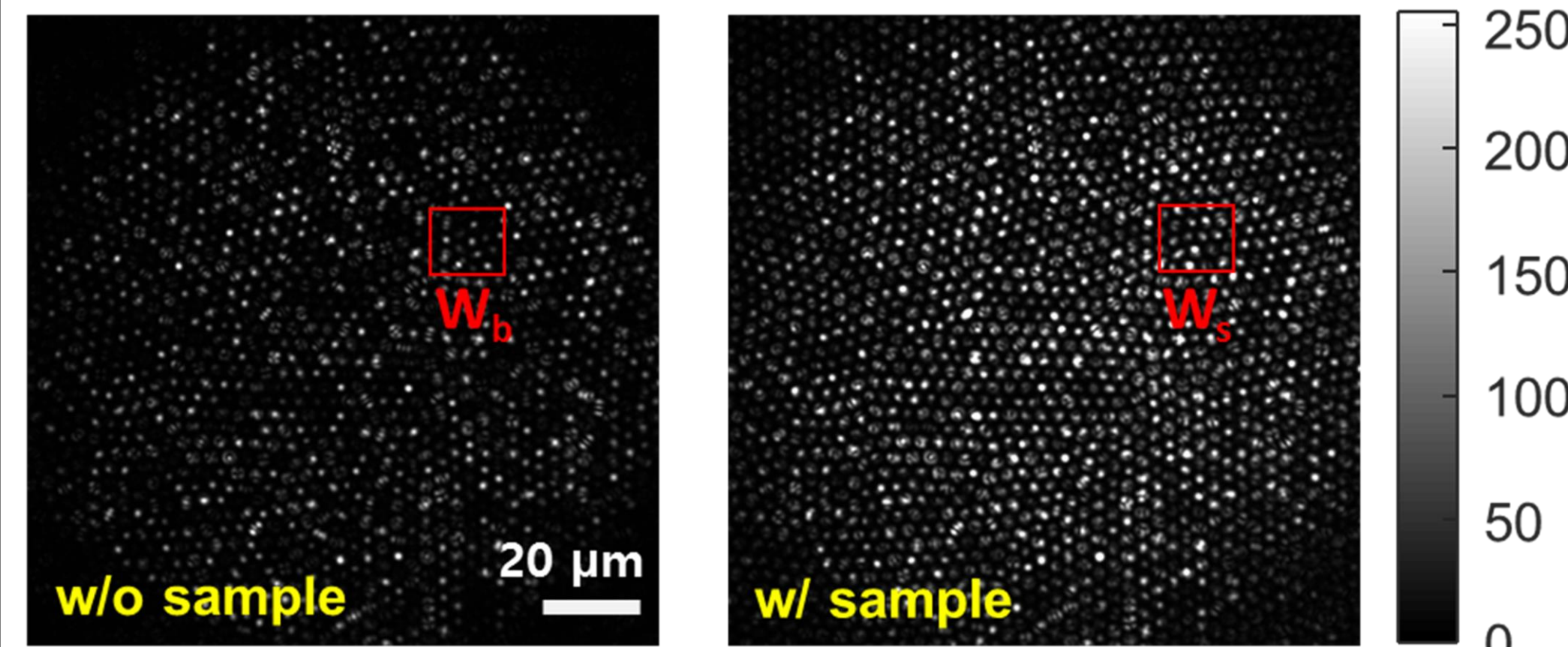
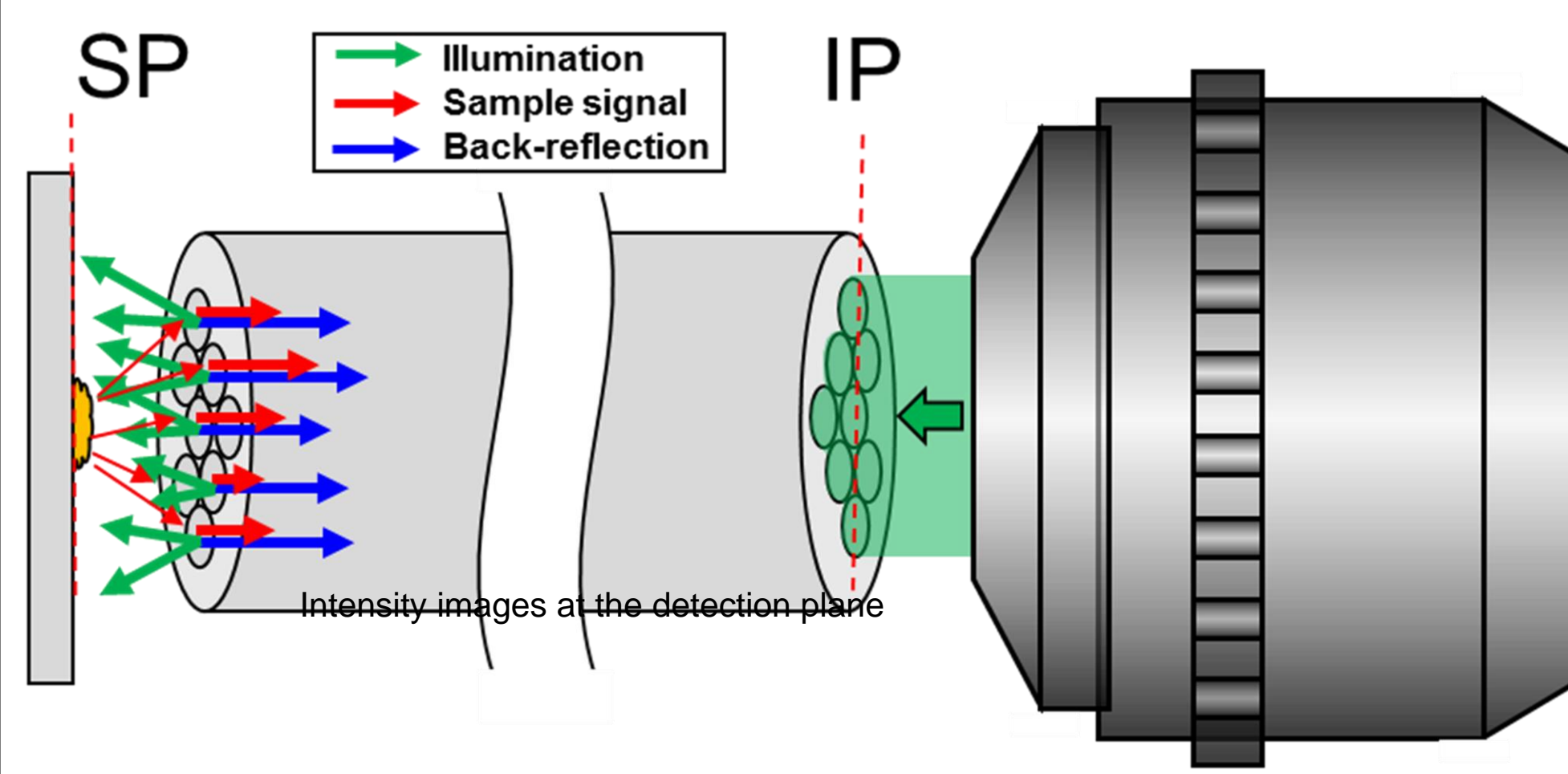
- Endoscope should work in reflection mode
- Twofold distortions need to be resolved
 - Distortion of illumination on the way in: IP → OP ← Speckle imaging
 - Image distortion on the way back: OP → IP ← Transmission matrix

Imaging villus in the rat intestine

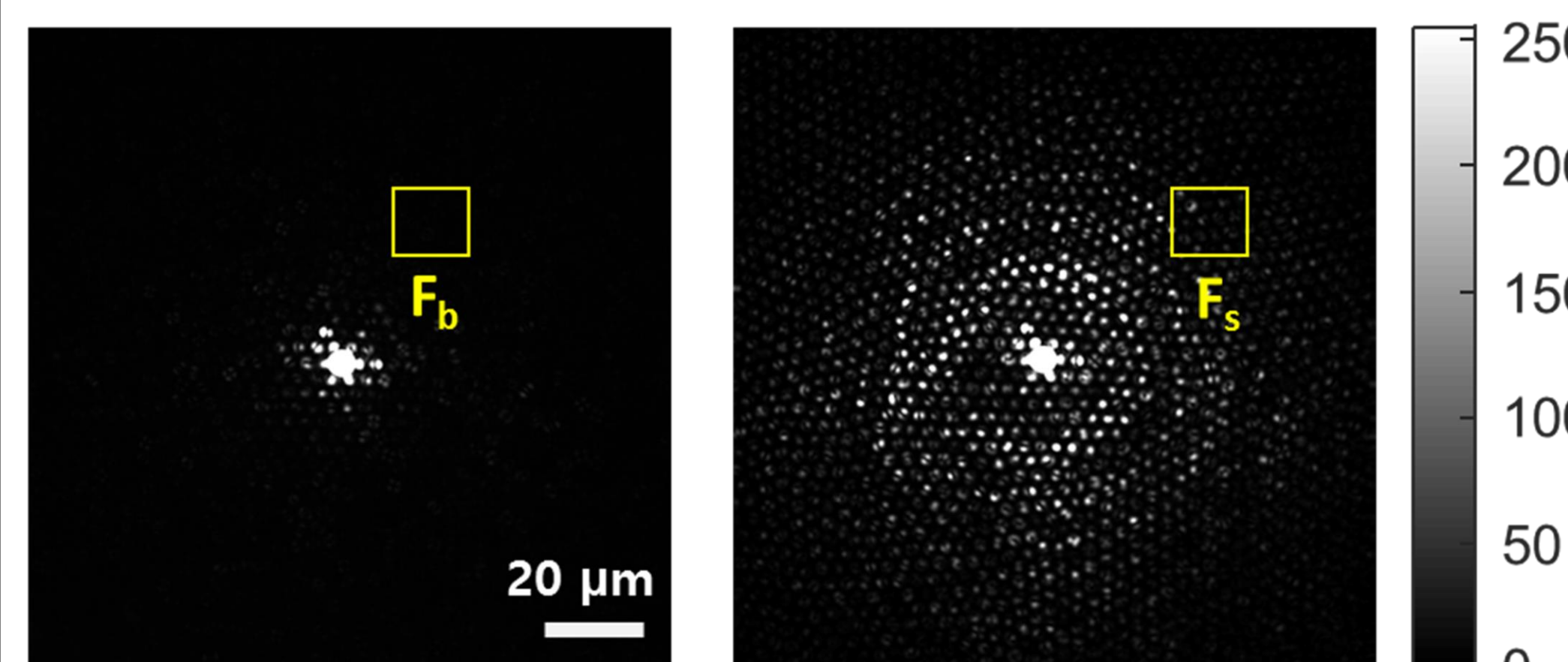
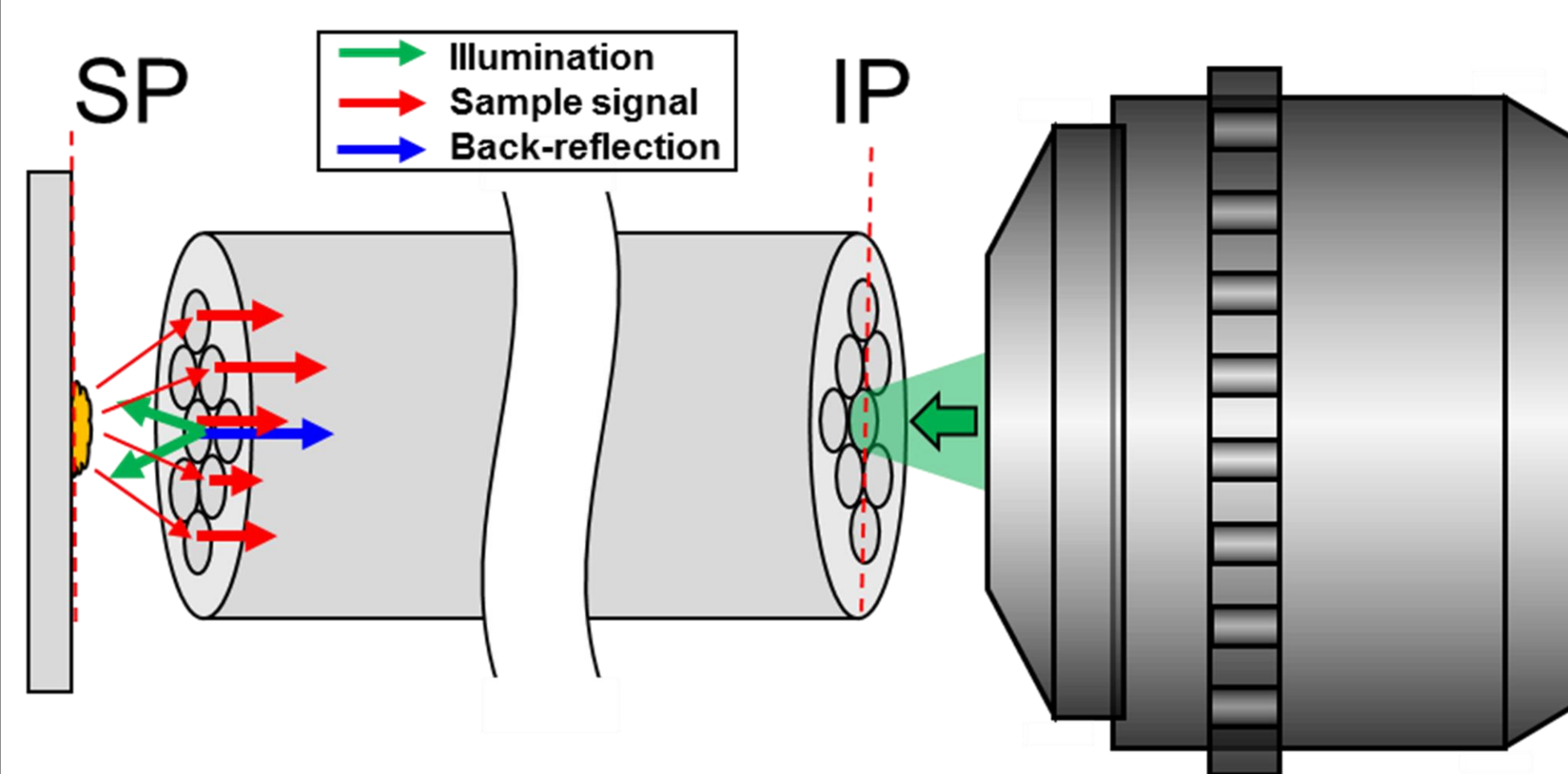


Y. Choi et al., Physical Review Letters **109**, 203901 (2012) (Selected as an editor's suggestion)

Reduction of back-reflection noise : Single-core illumination and wide-field detection method



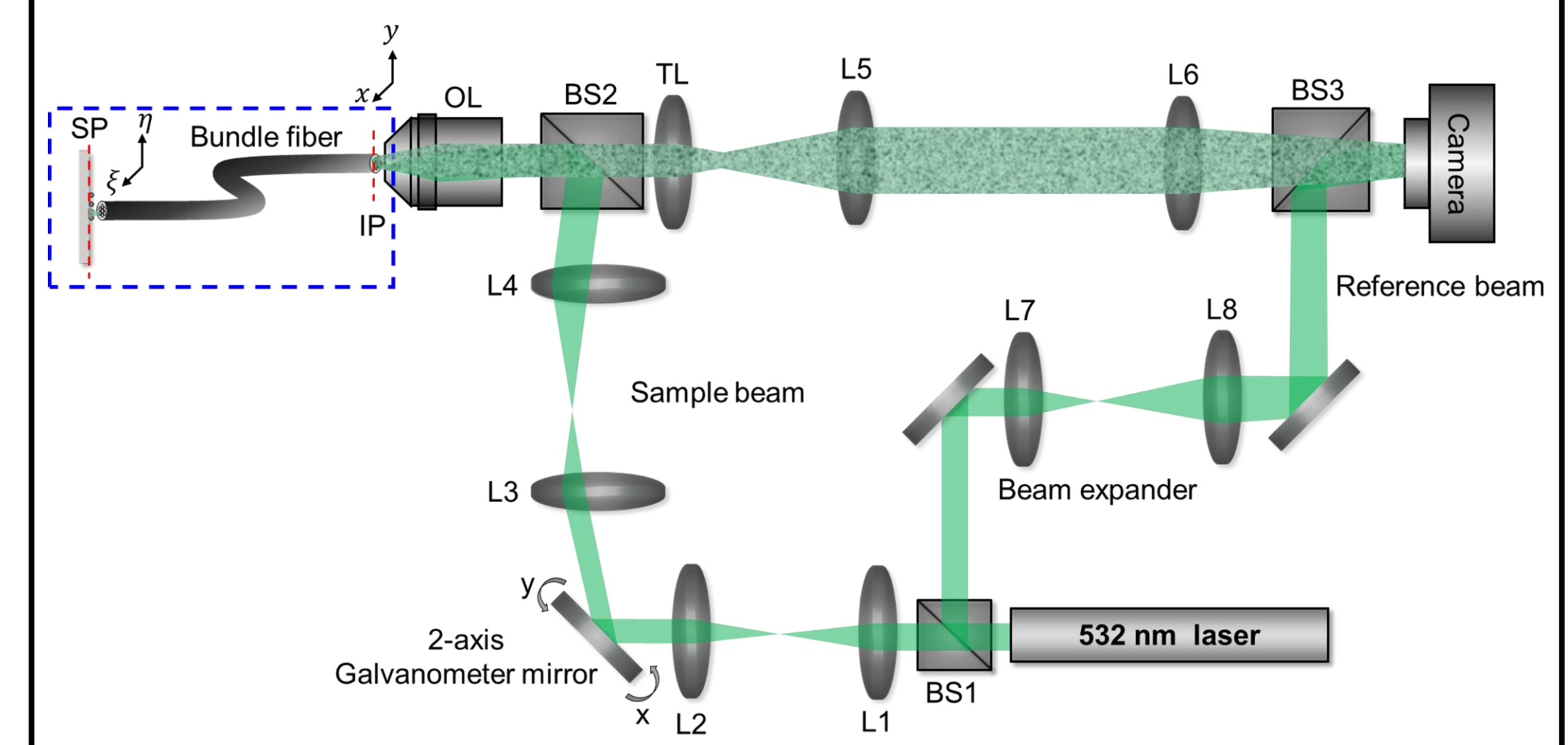
- Wide-field illumination and wide-field detection (WIWD)
- Signal to back-reflection ratio $\frac{W_s}{W_b} < 2$



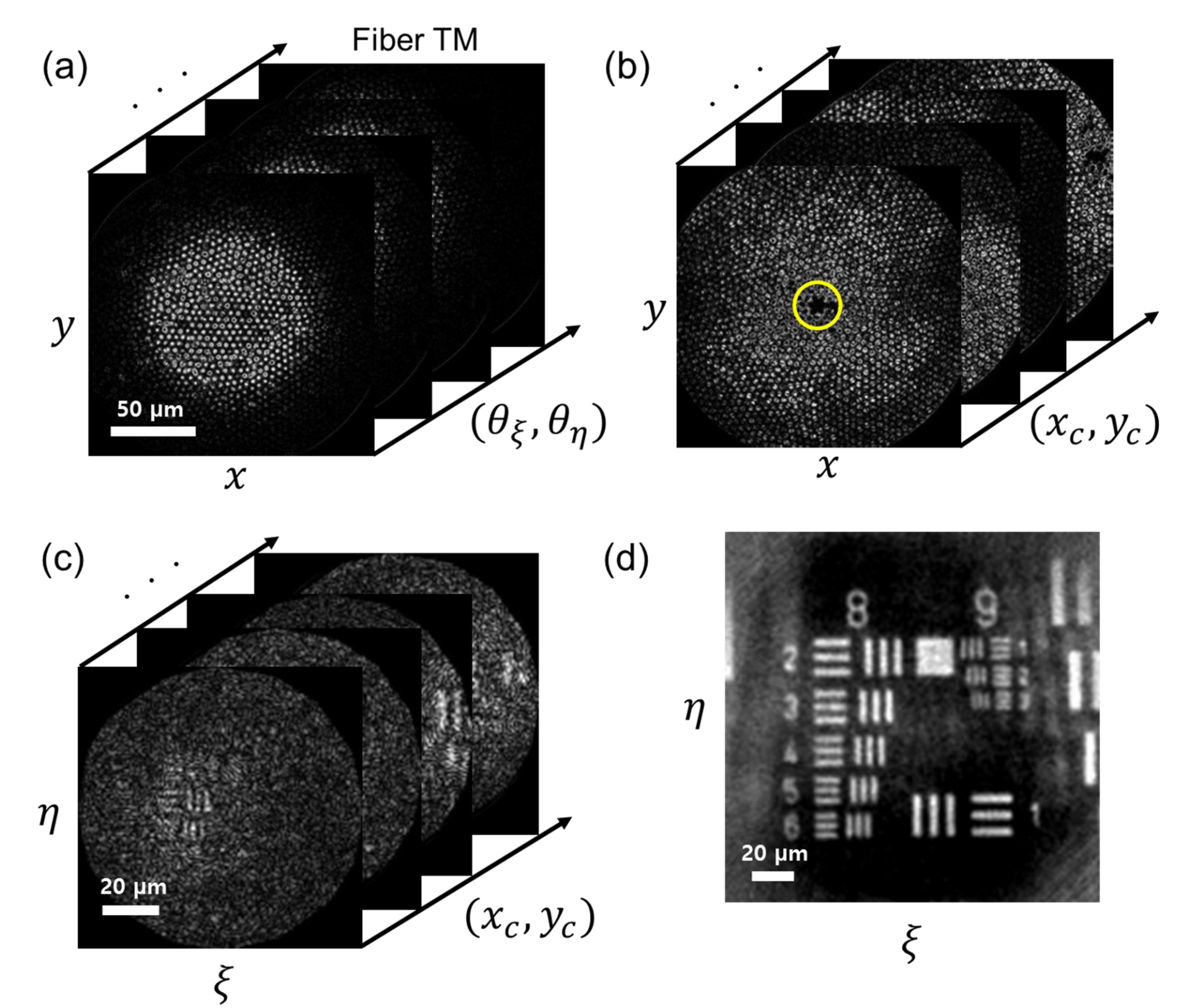
- Single-core illumination and wide-field detection (SIWD)
- Signal to back reflection ratio $\frac{F_s}{F_b} > 10$

- The strong reflection from the surface of a probe spoils the image contrast
- Using an image bundle fiber, we can separate the illumination fiber and detection fiber

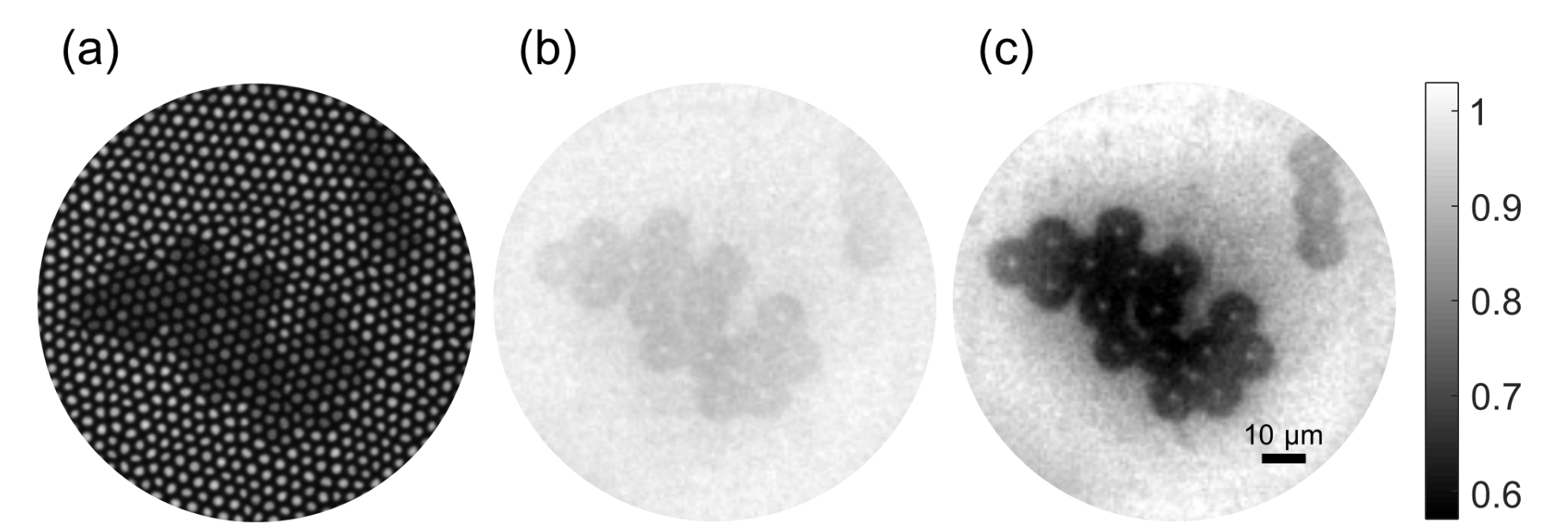
Experimental results



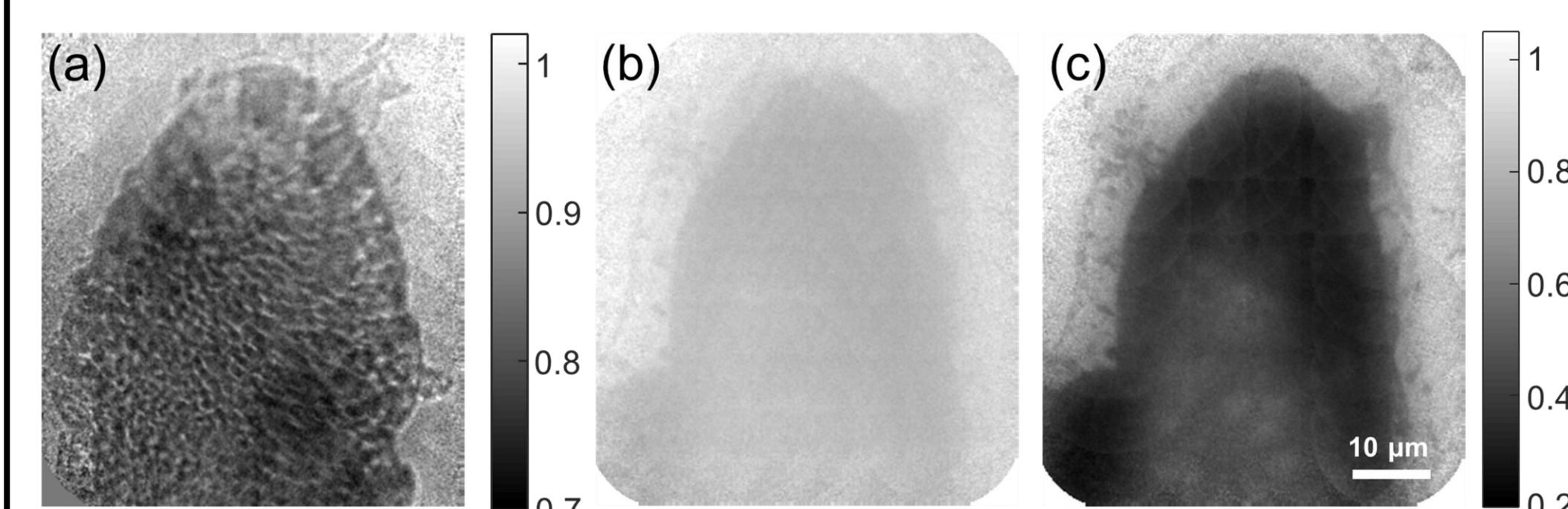
- Interferometric system for complex field measurement
- 2-axis galvanometer mirror scan the focused beam for sample illumination



- (a) Transmission matrix of the bundle fiber
- (b) Detected sample signal
- (c) Reconstructed images
- (d) Final sample image



- (a) LED epi-illumination, the beads are on the surface of the fiber
- (b) Reconstructed image, the beads are 100 μm from the distal end. (WIWD)
- (c) With the SIWD method



- Ex vivo imaging of a small villus of a rat intestine
- (a) WIWD in oil (b) WIWD in air (c) SIWD in air
- SNR of SIWD is 3.2 times better than the WIWD method

C.Yoon et al., Scientific Reports **7**, 6524 (2017)

Reference

- [1] Youngwoon Choi, Changhyeong Yoon, Moonseok Kim, Taeseok Daniel Yang, Christopher Fang-Yen, Ramacandra R. Dasari, Kyoung Jin Lee, and Wonshik Choi, "Scanner-Free and Wide-field Endomicroscopic imaging by Using a Single Multimode Optical Fiber", Phys.Rev.Lett. **109**, 203901 (2012)
- [2] Changhyeong Yoon, Munkyu Kang, Jin H. Hong, Taeseok D. Yang, Jingchao Xing, Hongki Yoo, Youngwoon Choi, and Wonshik Choi, "Removal of back-reflection noise at ultrathin imaging probes by the single-core illumination and wide-field detection", Sci.Rep. **7**, 6524 (2017)
- [3] Sungsam Kang, Seungwon Jeong, Wonjun Choi, Hakseok Ko, Taeseok D. Yang, Jang Ho Joo, Jae-Seung Lee, Yong-Sik Lim, Q-Han Park and Wonshik Choi, "Imaging deep within a scattering medium using collective accumulation of single-scattered waves", Nat.Photon. **9**, 253-258 (2015)