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Imaging by SOI Waveguides

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Abstract: *We show that silicon waveguides can simultaneously be utilized as focusing device and also as detectors in nonlinear fluorescence imaging. Detection and imaging of <20µm erbium particles by using 1550nm excitation are demonstrated experimentally.*

Nonlinear fluorescence imaging is an effective technology in 3D imaging of various elements such as biological tissues [1, 2]. Conventional nonlinear fluorescence imaging utilizes high numerical aperture objective lens to focus the beam on the imaging sample and photodetector to collect the fluorescence emission in a bulky free space setup. Semiconductor waveguides provide tight mode confinement due to large index contrast between the core and the cladding and act as a high numerical aperture lens [3]. Additionally, they can be used as photodetectors for photon energies exceeding the bandgap. In this paper, we introduce a multi-photon imaging system by using a silicon waveguide to deliver high intensity beam and to detect the fluorescence by using the same material. Experimentally, we excite erbium at 1550nm by using silicon waveguides, and then collect two and three photon fluorescence at 980nm and 540nm by using silicon p-i-n diode [4]. Experimentally we show imaging of <20µm erbium particles. Results indicate that compact multi-photon imaging systems can be developed based on planar technology.

In order to use a semiconductor material as an excitation medium and detection medium, the semiconductor should be transparent at the excitation wavelength and absorbing at the fluorescence wavelength. To satisfy these conditions for silicon, one has to use lasers >1.1µm to create multi photon fluorescence. To demonstrate proof of concept of planar multi-photon microscopy we select telecom lasers for excitation. As an imaging medium erbium doped Y_2O_3 micro-particles with 10-20 micron diameter has been utilized. Due to the strong up conversion, erbium provides strong two photon fluorescence at 980nm and three photon fluorescence at 540nm. Silicon is absorbing both wavelengths and it can be used as a detector. To deliver high intensity beam with 5µm^2 beam area, a 1550nm laser is coupled into a silicon waveguide. Then the coupled light is launched onto erbium doped particles placed in front of the waveguide output. A silicon photodiode is used as a detector. After scanning the 20µmx20µm image area the raw image data is collected, Fig.1. The raw image data is then

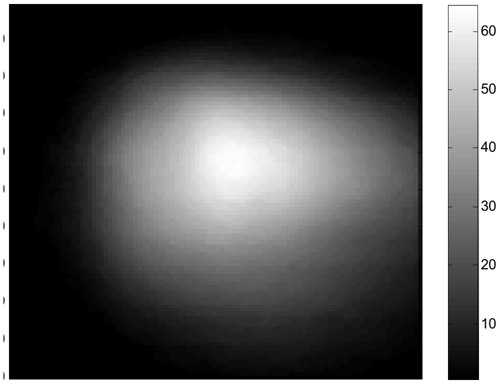

Figure 1. The raw image obtained from scanning.

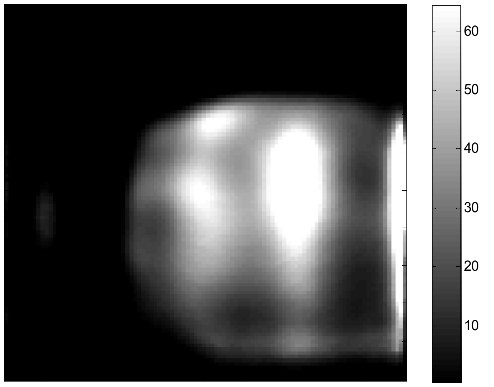

Figure 2. The deconvolved image obtained with measured initial field.

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deconvolved with the point spread function of the waveguide at the image plane and the actual image pattern is created, Fig.2 [5]. The results show the image of multiple particles with sizes varying from 4μm to 20μm can be resolved successfully. Further optimization in image processing is possible to obtain higher resolution imaging [6].

The waveguides used in this experiment have p-i-n diode structure which provides simultaneous detection capability. However, for high sensitivity the detector should be optimized and p-n junctions should be placed at the tip of the waveguide. Although the current set up fall short of delivering simultaneous excitation and detection capability due to non optimum diode structure and low sensitivity, we show that waveguide tips indeed can be used as a detector to image fluorescence generated in erbium doped fibers. Figure 3 illustrates the imaging of a 4μm diameter erbium doped fiber tip scanned by the silicon waveguide which is used as a transmitter to excite the medium at 1550nm and as a detector.

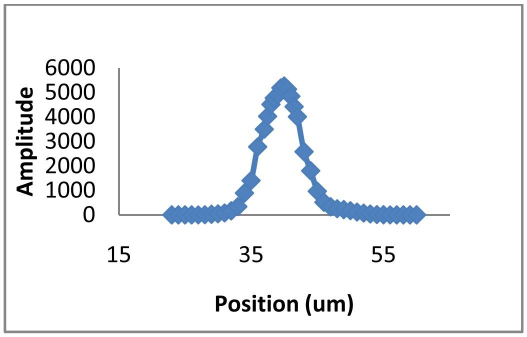

Figure 3. The photocurrent dependence with vertical scanning position.

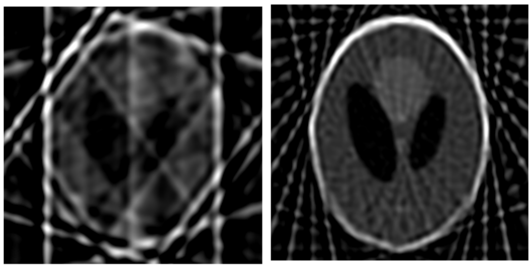

Figure 4. The reconstructed images of two round objects, which received scattering by using five transmitters and 36 transmitters.

Theoretical estimates show that planar technology can be effective in imaging of micron size particles by using multi-photon fluorescence and scattering. Due to compact size, multiple transmitters and receivers can be integrated on the same platform to have high resolution imaging. Figure 4 illustrates the reconstruction of two round objects, similar to pattern expected in cell imaging based on scattering by using five transmitters and 36 transmitters, respectively. Results indicate that high resolution imagings of micron size objects are achievable. Number of transmitters and receivers can be reduced if both scattering and fluorescence is used in a planar domain.

In summary, we show that semiconductor based planar waveguide technology can be effective tool in multi-photon imaging. While high intensity beam is delivered by tight mode confinement in the waveguide, the tip of the same waveguide can be utilized as detector for the multi-photon fluorescence. Experimentally we present imaging of micron size $Er^{3+}:Y_2O_3$ particles by using silicon waveguides and 1550nm excitation.

Reference

[1]W. Denk, J. H. Strickler, and W. W. Webb, "2-Photon Laser Scanning Fluorescence Microscopy," *Science,* vol. 248, pp. 73-76, Apr 6 1990.
[2] Webb, G. Andrew*, Introduction to Biomedical Imaging*, Wiley, 2002.
[3] R. Soref, "Silicon-based optoelectronics," *Proc. IEEE* vol. 81, pp.1687-1706, 1993.
[4]D. Marris-Morini, X. Le Roux, L. Vivien, E. Cassan, D. Pascal, M. Halbwax, S. Maine, S. Laval, J. M. Fedeli, and J. F. Damlencourt, "Optical modulation by carrier depletion in a silicon PIN diode," *Optics Express,* vol. 14, pp. 10838-10843, Oct 30 2006.
[5] V. Krishnamurthi, Y. H. Liu, S. Bhattacharyya, J. N. Turner, and T. J. Holmes, "Blind Deconvolution of Fluorescence Micrographs by Maximum-Likelihood-Estimation," *Applied Optics*, vol. 34, pp. 6633-6647, Oct 10 1995.
[6] P. Sarder and A. Nehorai, "Deconvolution methods for 3-D fluorescence microscopy images," *Ieee Signal Processing Magazine*, vol. 23, pp. 32-45, May 2006.