Fourier Domain Optical Coherence Microscopy with extended depth of field

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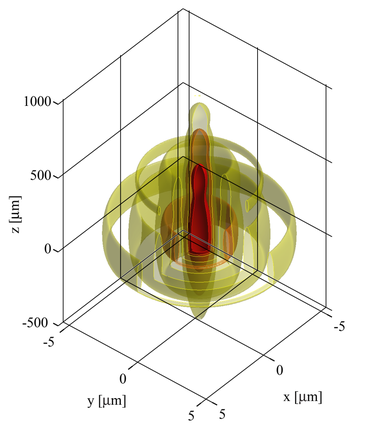
Program in Photonics

Doctoral

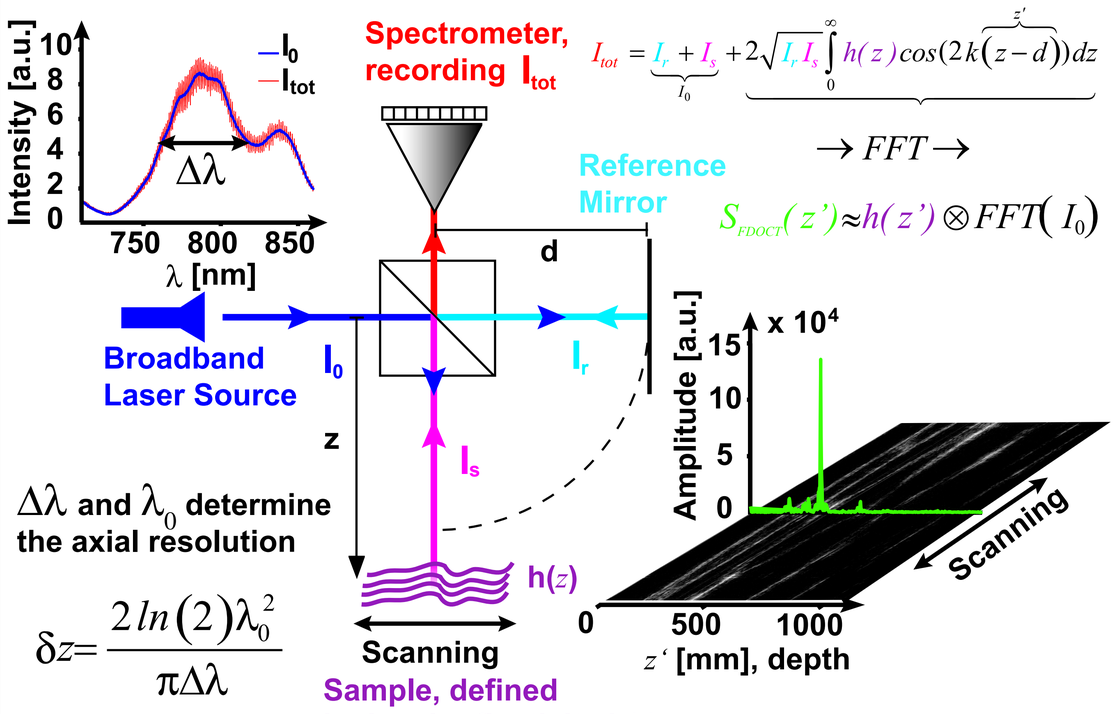


Intensity distribution in the focal zone for the extended DOF setup. The surfaces indicate the $1/e$,$1/e^2$ and $1/e^3$ locations of the maximum value.

Motivation

Fourier Domain Optical Coherence Tomography (FDOCT) is a high speed biomedical imaging modality which extracts the sample structure in depth. The axial resolution is given by the coherence length of the employed light source. The lateral resolution on the other hand is determined by the numerical aperture (NA) of the objective. The parallel detection of the depth information has the drawback of loosing transverse resolution along the optical axis, limiting the depth of field (DOF) and the use of FDOCT in the field of microscopy. The principle idea to overcome this problem is to illuminate the sample with a cylindrically symmetric interference pattern. Such Bessel beam illumination creates a laterally highly confined needle extending several 100µm along the optical axis in depth.

FDOCT Method



$$I_{tot} = \underbrace{I_r + I_s}_{I_0} + \underbrace{2\sqrt{I_r I_s}\int_0^\infty h(z)\cos(2k\overbrace{(z-d)}^{z'})dz}_{\rightarrow FFT \rightarrow}$$

$$S_{FDOCT}(z') \approx h(z') \otimes FFT(I_0)$$

$$\delta z = \frac{2\ln(2)\lambda_0^2}{\pi\Delta\lambda}$$

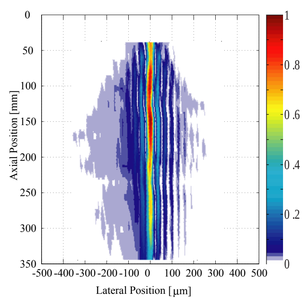
Extended depth of field

In classical illumination, the lateral resolution and DOF are related:

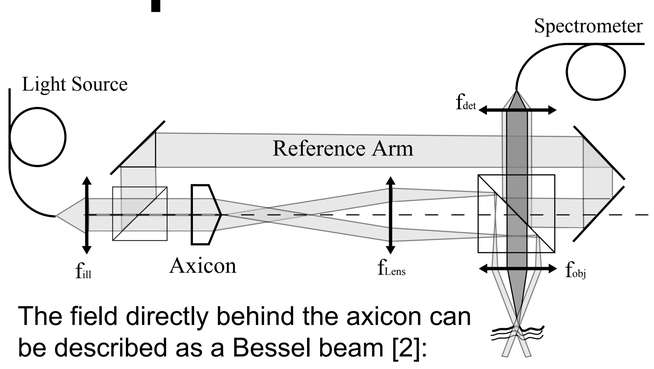
$$\delta x = \frac{\lambda}{\pi NA}, \quad \mathrm{DOF} = \frac{2\lambda}{\pi NA^2}$$

Using a conical lens (axicon) to create a Bessel beam extends the DOF [1]:

$$\delta x = \frac{1.2\lambda}{\pi NA}, \quad \mathrm{DOF} \propto \frac{\omega_{ill}}{NA}$$



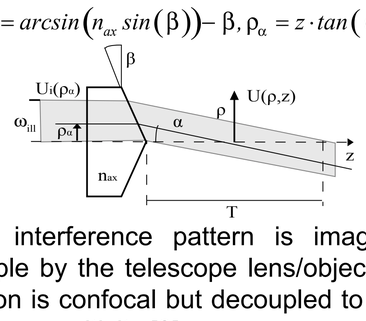
Intensity distribution behind an axicon with β = 1°.



The field directly behind the axicon can be described as a Bessel beam [2]:

$$U(\rho, z) \propto \sqrt{\rho_\alpha}\, U_i(\rho_\alpha) J_0(k\rho \sin(\alpha)),$$

$$\alpha = \arcsin(n_{ax}\sin(\beta)) - \beta, \quad \rho_\alpha = z \cdot \tan(\alpha)$$

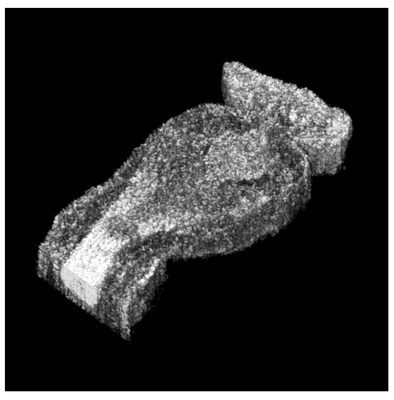


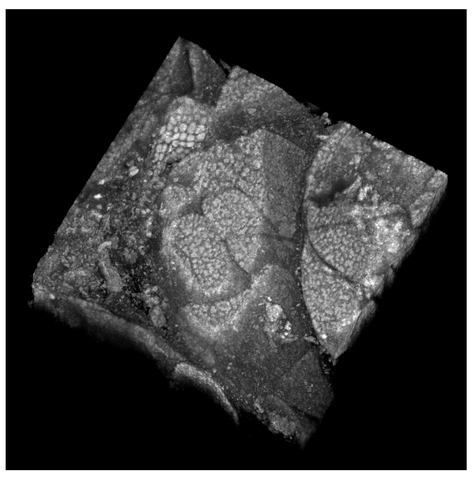
This interference pattern is imaged into the sample by the telescope lens/objective. The detection is confocal but decoupled to increase detection sensitivity [3].

Results

Developmental Biology (LDCS*)

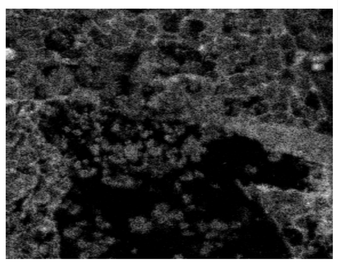
The easily accessible hair follicle allows to study cellular and molecular mechanisms that control linage specification. The tomogram below shows a rat follicle (200x500x60µm).

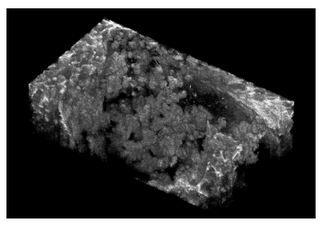




Oncology (ISREC****)

The images to the right show an area of 800x800µm of mouse breast with lactic ducts embedded in fat tissue. These ducts build a complex ramified structure, which plays an important role in understanding breast cancer.

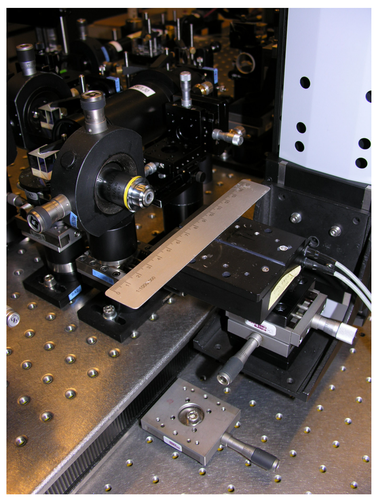




Diabetes Research (SV**, CMU***)

The amount and functionality of islets of Langerhans in the endocrine pancreas are of particular interest in diabetes research. They contain the secretory β-cells which produce insulin. However, the islets only represent about 2 vol.% of the entire pancreas. The tomogram to the left shows 1.5x1.5mm ot the lobular structure of exocrine rat pancreas.

System Parameters



- Axial resolution of 3µm
- Lateral resolution of 1.5µm
- over a depth range of 200µm
- High sensitivity of 105 dB

References

[1] Z. H. Ding, H. W. Ren, Y. H. Zhao, J. S. Nelson, and Z.P. Chen, Opt. Lett. 27, 243 (2002).
[2] R. M. Herman and T. A. Wiggins, J. Opt. Soc. Am. A 8, 932 (1991).
[3] R. A. Leitgeb, M. L. Villiger, A. H. Bachmann, L. Steinmann, and T. Lasser, Opt. Lett. 2450(2006).

Acknowledgements

-SNF Project 205321-10974
-*Laboratoire de Dynamique des Cellules Souches (LDCS), Yann Barrandon, EPFL
-**Sience de la Vie (SV), William Pralong, EPFL
-***Centre Médicale Universitaire (CMU), Paolo Meda, Genève
-****Institut Suisse de Recherche Expérimentale sur le Cancer (ISREC), Cathrin Brisken

Conclusion and Outlook

- Extended DOF by use of an axicon
- High image contrast, unachievable for classical microscopy without fluorescent or labeled samples
- Application in current biological research

→Comparison of OCT data with histology of the samples
→Implementation of beam steering for faster scanning
→Combination with fluorescence microscopy for functional imaging

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