A fiber-based endomicroscope designed for full Mueller endoscopic polarimetric imaging

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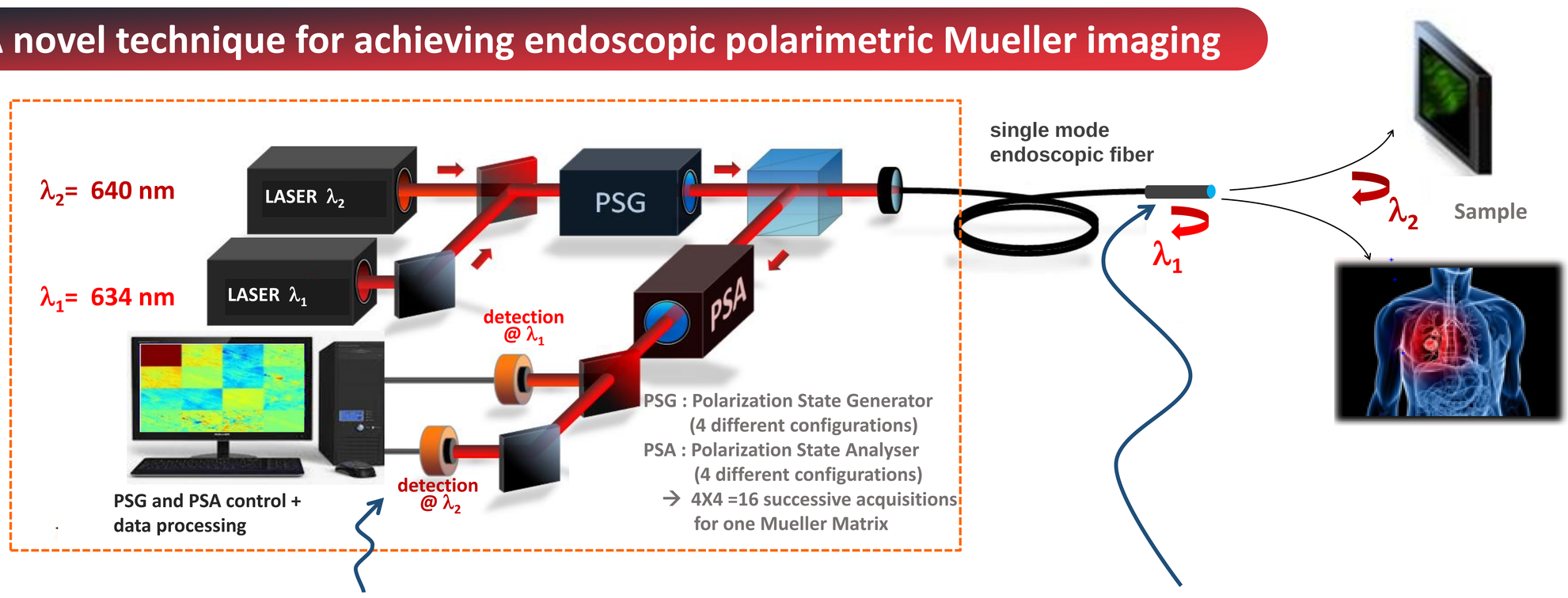
[1]*Institut de Recherche Xlim, UMR CNRS 7252, Université de Limoges, 87060 Limoges, France*
[2]*Université Paris Saclay, LPICM, CNRS, Ecole Polytechnique, 91128 Palaiseau, France*
[3]*Université de Mons, Faculté Polytechnique, B-7000 Mons, Belgium*

Context and objectives

Mueller polarimetry: a powerful technique allowing the determination of all the polarimetric characteristics of a sample from a 4x4 Mueller matrix (M_{samp}).
A promising application…: early diagnosis of diseases affecting biological tissues [1].
… but a serious limitation: since an optical-fiber-based endoscope behaves as an uncontrollable time dependent polarization scrambler, the use of such an instrument seems incompatible with polarimetric imaging: polarimetric imaging is limited to external tissues or biopsies.
The challenge to overcome: how to get rid of the harmful polarimetric effects of the fiber for allowing polarimetric endoscopic imaging of inner tissues?

A novel technique for achieving endoscopic polarimetric Mueller imaging



Two-wavelength differential method (TWDM) based on a simultaneous measurement at two close wavelengths [2]

@λ_1 ➡ $M_{\lambda 1}$ = matrix "fiber only" = $M_{Back1} . M_{Forth1}$
determination of M_{Back1} and M_{Forth1}

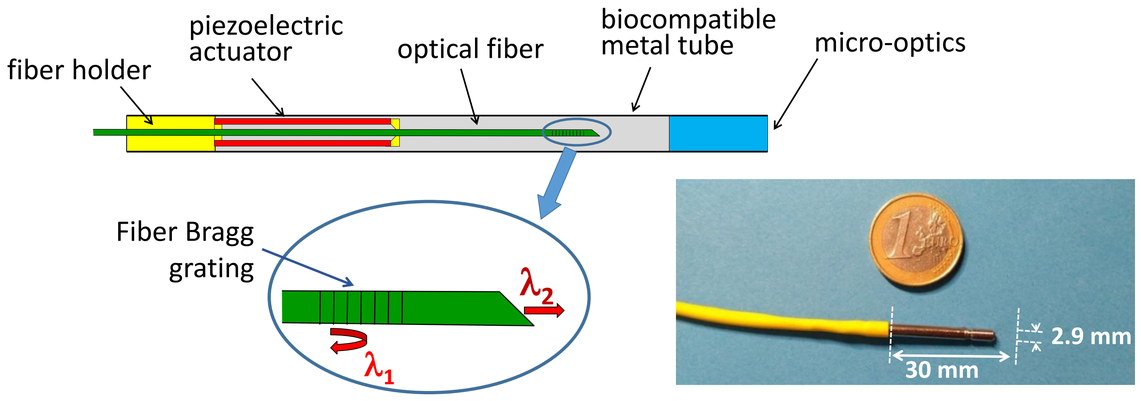
@ λ_2 ➡ $M_{\lambda 2}$= matrix "fiber +sample" = $M_{Back2} . \boxed{M_{Samp}} . M_{Forth2}$

If λ_1 and λ_2 are close enough ($\Delta\lambda < 1\%$), thus:

$$M_{Forth1} \sim M_{Forth2} \text{ and } M_{Back1} \sim M_{Back2}$$

➡ $M_{\lambda 2} \sim M_{Back1} . \boxed{M_{Samp}} . M_{Forth1}$ ➡ $\boxed{\mathbf{M_{Samp}}} \sim \mathbf{M_{Back1}^{-1} . M_{\lambda 2} . M_{Forth1}^{-1}}$

Specially designed microprobe making it possible to implement the TWDM [3]

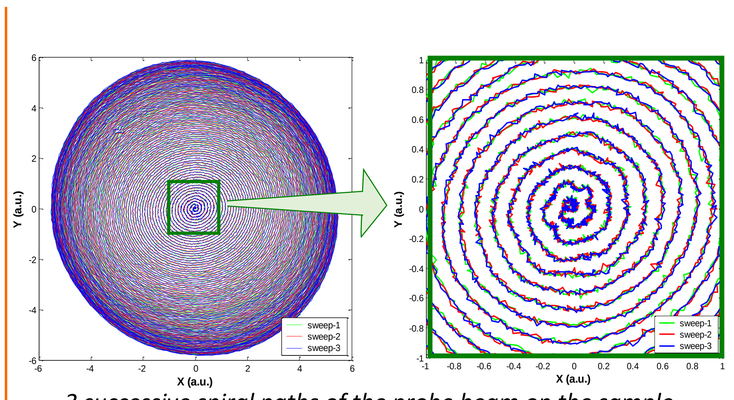


Experimental performances and example of polarimetric endoscopic image

For each pixel of the sample → determination of the associated Mueller matrix M_{samp} by means of the TWDM → Lu-Chipman decomposition of M_{samp} → **remote determination of all the polarimetric characteristics** of this pixel:

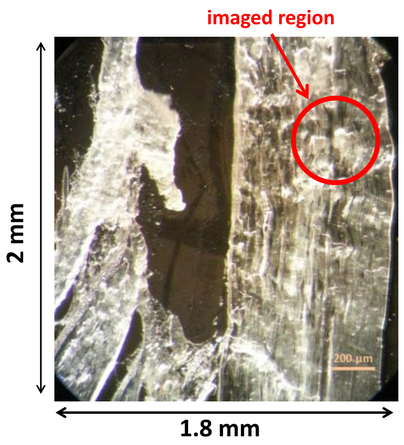
- **linear retardance (precision of +/- 3°):** *effect of birefringence in fibrillar tissues*
- **depolarization rate (*):** *effect of volume scattering of light in the tissue*
  - *diagnosis of diseases like fibrosis or certain cancers which affect the structure of the tissue at the submicronic scale, inducing changes in retardance and /or depolarization.*
- **diattenuation (precision < 0.02):** effect of anisotropic absorption or diffusion of light
  - *detection of specific biomolecules*
- **relative direction of the birefringence/diattenuation eigenaxes (precision of +/- 1°)**
  - *precise topological characterization of collagen fibers and fibrils*

(*) concerning the depolarization measurement, the precision depends on the measuring conditions

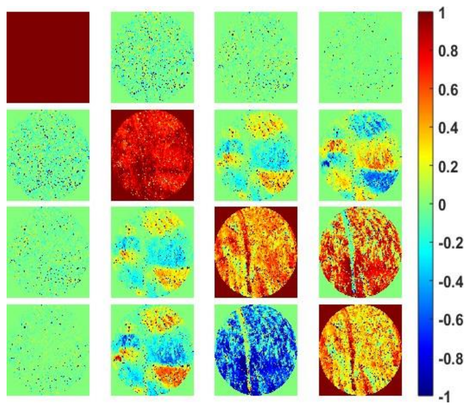


3 successive spiral paths of the probe beam on the sample

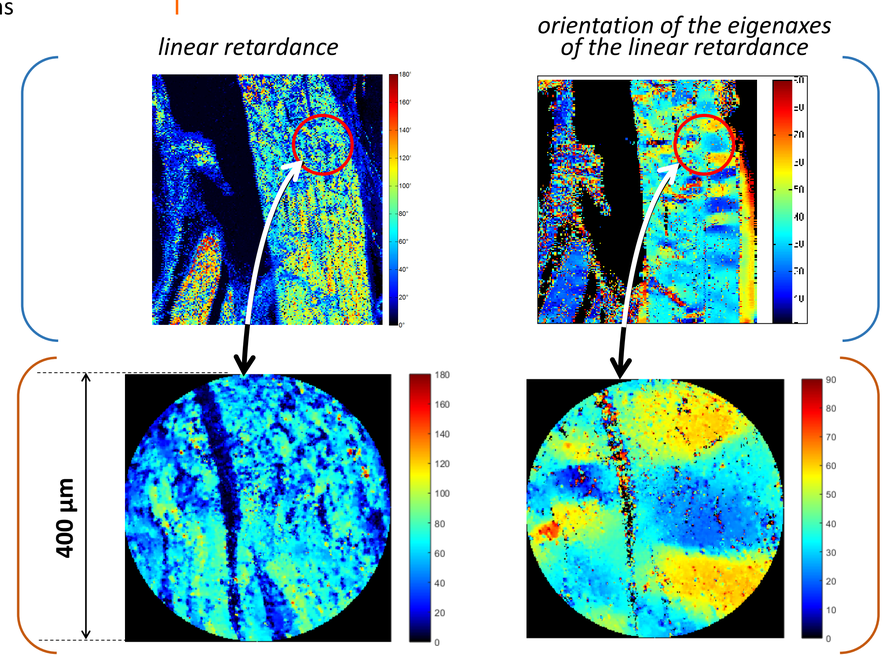
- typical circular field of view: 400µm
- reachable field of view: Φ = 1mm
- resolution: 4µm
- acquisition time for one PSG/PSA configuration (250 X 250 pixels) = 125ms
- dwell time: 1.7µs
- excellent repeatability of the probe beam path (see images on the left)
- one polarization image (requiring 4 X 4 successive acquisitions) achieved every 2s



raw image of a rat tendon sample



Mueller Matrix of the imaged region



with a point by point bulk imaging scanner
180 X 200 pixels
production time = 20min [2]

with the microprobe shown above
250 X 250 pixels
production time = 2s [3]

References

[1] V.V. Tuchin et al., "*Optical Polarization in Biomedical Applications*", Springer, ISBN 3-540-25876-0 (2006)
[2] Vizet et al., J. Biomed Optics 21, 7, 071106 (2016).
[3] Buckley et al., Biomed Opt Express 11, 12,7032 (2020).

Contacts

dominique.pagnoux@xlim.fr
marc.fabert@xlim.fr

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