controllers (PC1 and PC2) attached to the SMFs act like a fast saturable absorber based on nonlinear polarization evolution (NPE). A bulk optical isolator (ISO) was placed in the free space for unidirectional ring cavity operation so that the saturable absorber based on NPE becomes effective and the mode-locking operation becomes self-starting. The laser cavity was made with all-normal-dispersion elements (net GVD ~0.12 ps^2) and no negative dispersing element like a grating pair is present inside the cavity for the dispersion compensation. For the purpose of pulse width management a narrow band interference filter (bandwidth 10 nm, peak transmission ~1064 nm) is placed after the PBS. The output was taken directly at NPE rejection port. Since the laser was made of all-normal dispersion components the pulses are chirped and compressed externally using a grating pair placed in a near littrow configuration. By adjusting the polarization controller a train of mode-locked pulses are readily observed at a pump power of 280 mW. Fig. L.4.2 shows the oscilloscope trace of the mode-locked pulse train. It can be seen from Fig.L.4.2 that the mode- locked pulse train was fairly stable at a repetition rate of 37 MHz. By adjusting the NPE the laser can be operated in various modelocking regimes.

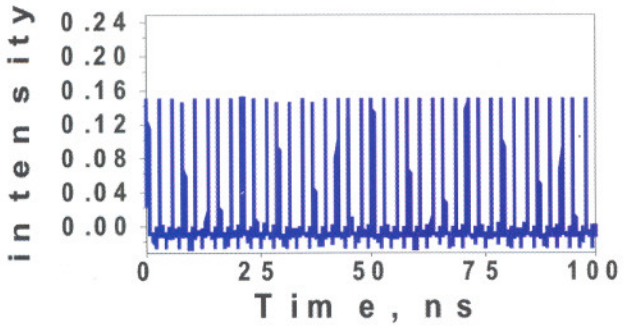

Fig.L.4.2: Oscilloscope trace of the recorded pulse train

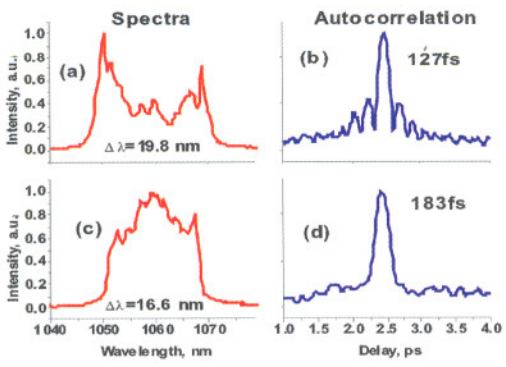

Fig.L.10.3 Spectra and the corresponding autocorrelation trace of the mode-locked pulses

In Fig.L.4.3 the spectra and the corresponding different autocorrelation traces are shown. In one regime the spectra is broad and the compressed pulse duration was measured to be 127 fs. However, the compressed pulse was accompanied with side-lobes. In another regime relatively smooth pulse was obtained, however, the pulse duration was some what broader ~187 fs. The average power of the compressed modelocked pulses was measured to be 50 mW corresponding to 1.4 nJ of pulse energy

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L.5: Swept source based fiber-optic polarization sensitive optical coherence tomography setup for near real-time imaging of tissue birefringence

Polarization sensitive optical coherence tomography (PSOCT), an extension of optical coherence tomography (OCT), can be used to provide the cross-sectional images of tissue microstructures and birefringent constituents of the tissue in real time. In contrast to bulk-optic setups, fiber based setups provide relatively stable alignment and can be coupled to endoscopic probes, thereby facilitating in-vivo applications. Zhao et al have recently described a polarization measurement scheme that uses a polarization modulator in the sample arm of a free space spectral domain PSOCT setup. Since this method requires only the intensity measurements for the determination of polarization parameters, it is expected to be insensitive to the jitters present in swept source. We have therefore developed a single mode fiber based swept source PSOCT (SS-PSOCT) setup with a linear polarizer and a polarization modulator in the sample arm to measure the polarization parameters of the sample.

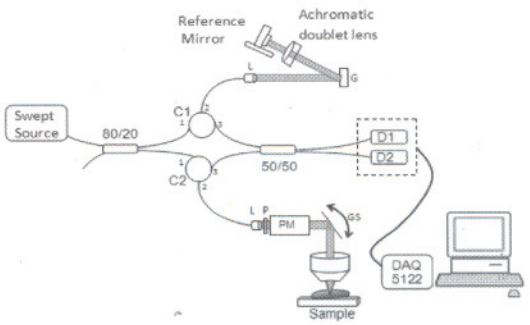

Fig. L.5.1. Schematic of the SS- PSOCT set-up: C1, C2-circulators, D1 and D2-balanced detectors, G-grating, GS-galvoscanner, L-collimating lenses and P-linear polariser, PM-polarization modulator.

The PSOCT setup (Fig. L.5.1) developed at LBAID, RRCAT uses a swept laser source (Thorlabs SL1325-P16) which has average power output of ~ 12 mW and whose wavelength can be tuned over a 110 nm range around the 1325 nm central wavelength with a sweep rate of 8 kHz. Light coming from the source is introduced into a fiber based Mach Zhender

interferometer. The sample arm of the interferometer comprises of a fiber collimator lens, polariser, an electro-optic polarization modulator (PM), a galvo-scanner mirror, and an objective lens. The PM was used to illuminate the sample with desired incident polarizations. We employed in the reference arm of the interferometer, an optical arrangement, similar to the Fourier domain optical delay line in order to minimize the dispersion mismatch in the interferometer. Three different polarization states of light were used to illuminate the sample sequentially. For each incident polarization, the light back-reflected from both the reference and sample arms is collected by a 50/50 coupler and coupled to an InGaAs balanced photo receiver. The interferometric signal was digitized using a high-speed data acquisition board (NI-5122). The measured interferogram signal was processed (wave number-resampling, dispersion compensation, FFT) to provide the depth resolved reflectivity, birefringence and optic axis orientation profile of the sample. LabView based software was developed to control the entire setup and for signal processing along with image display. The signal to noise ratio (SNR) of the setup was ~95 dB. The axial and lateral resolutions of the setup were ~12 μm and ~30 μm (with a 5X objective lens in sample arm) respectively. The imaging speed of the setup was ~6 frames per second (fps) for OCT intensity images and ~2 fps for PSOCT images.

For calibration of the SS-PSOCT setup, the retardance of a quarter wave plate was measured for different orientations (from 0° to 360° in steps of 10°) of its fast axis in a plane perpendicular to the light path. The average retardation value for 0° to 360° fast axis orientation was measured to be 176.5° with standard deviation 2.5°. The setup has also been used to obtain intensity, retardation and fast axis orientation images of the nail fold of a healthy human volunteer in-vivo (Fig. L.5.2).

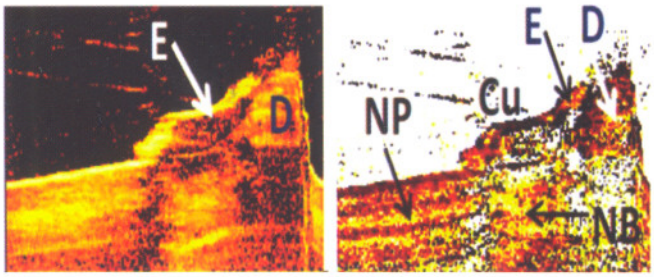

Fig.L.5.2. Intensity (left) and retardation (right) images of human nail fold. Cu: cuticle; D: dermis; E: epidermis; NB: nail bed; NP: nail plate; Image dimensions are 3mm (lateral) × 2mm (depth).

In summary, we have demonstrated a single detector based fiber-optic PSOCT scheme using a swept laser source for generating intensity, retardation and optic axis orientation images of biological tissues. With the rapid advances in swept source technology both in terms of the line rate and miniaturization, this scheme may find potential clinical applications for volumetric polarization sensitive imaging compared to the conventional intensity based data.

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L.6: Orientation and rotation of red blood cells with Laguerre-Gaussian trap beams

Red blood cells (RBCs) have a discotic shape and when optically trapped the cell orients itself in a side on or vertical configuration. Earlier we have developed methods for controlling the stable orientation of the trapped cells using either a combination of point and line tweezers or combination of cw and pulsed trap beams. Such control on orientation has important applications in recording polarized Raman spectra from optically trapped RBCs. Recently we carried out experiments at Laser Biomedical Applications and Instrumentation Division to explore the possibility of using Laguerre-Gaussian (LG) trap beam instead of conventional TEM_{00} trap beam to control the orientation of trapped RBCs. Further, since LG trap beams have orbital angular momentum associated with their helical wavefronts, experiments were also carried out to investigate use of these beams to rotate trapped RBCs. Such use of RBCs as micro-rotor has potential applications in microfluidics.

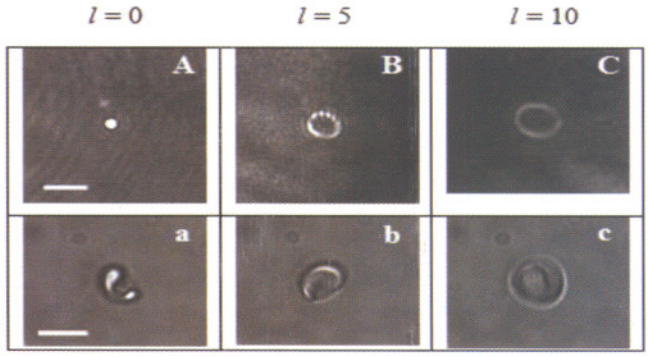

Fig.L.6 1: Trapping LG beam profiles for topological charges 0, 5 and 10 (A-C) and the corresponding orientation of a trapped RBC (a-c) respectively. Scale bar, 2.5 μm. (A-C) and 6 μm (a-c).

The LG modes have an annular intensity profile, size of which increases with the azimuthal index or topological charge of the mode. We observed that control over the orientation of the trapped RBC in the vertical plane could be achieved with a change in the topological charge of the trapping beam. Fig. L.6.1 shows the change in the orientation of a trapped RBC with changes in the topological charge of the LG modes. For the zeroth order LG mode (which is identical to TEM_{00}) the cell orients with its plane along the direction of the