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Development of a High Resolution Imaging System at 635nm and 840 nm

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Abstract: This Optical Coherence Tomography (OCT) is a non-invasive technology which is used in medical and non-medical applications to produce high-resolution images. It provides the cross-sectional images of an object in real time. It is based on low coherence inter ferometry to get the depth resolved information of the sample. The depth of imaging is in millimeter range with the resolution in the micrometer range. The broadband source of light is split by the beam splitter and directed to the sample arm and reference arm respectively as is the case in Michelson's interferometer. The CCD photo-detector used in the NIR spectrometer detects the interference produced by the backscattered light. The Matlab script is used to convert this backscattered data into an image pertaining to one axial scan (A-scan). Final 2D/3D image is constructed by performing A-scans at various points of the sample in the XY plane.

Keywords: Matlab, Michelson Interferometer, OCT, Photo-Detector, Reference Arm, Sample Arm, etc

I. INTRODUCTION

Optical Coherence Tomography (OCT) is a non-invasive imaging technique which is used to take the cross sectional images of any object or sample in the depth direction. The resolution is in micrometer range and the depth is in millimeter range. This technique is based on the Michelson Interferometer principle. OCT technique is similar to the Ultrasound sonography. The sound is used in ultrasound sonography while in OCT technique, the laser source is used. OCT is based on low coherence interferometry which utilizes broadband light source to get the higher resolution. The shorter wavelength is used to get more resolution. The axial resolution is the measure of how fine the structures can be resolved in the depth direction. The OCT technique can be used in various applications like ophthalmology, gastroenterology, dentistry, cancer diagnosis, cerebral blood flow detection etc. OCT performs the cross sectional imaging by measuring the magnitude and the echo time delay of the backscattered light. Measuring the echo time delay of several reflections generates the axial scans (A-scans). This set of A scans generates B scans which is a 2-D image. Further, this set of B scans generates a 3-D image. The types of OCT systems are: Time domain OCT, spectral domain OCT and swept source domain OCT. The spectral domain and swept source domain OCT techniques are more popular because of their fast acquisition time. The Zaber plates are used to scan the sample or an object in x and y direction. So that 2-D and 3-D images can be created by scanning the sample laterally as well as longitudinally. Here, mainly the broadband source is used to increase the axial resolution. The absorption is seen higher in the biological samples. The Matlab script is used to process the acquired data.

II. OCT AND OTHER IMAGING TECHNIQUES

The Magnetic Resonance Imaging (MRI) technique cannot resolve the object smaller than 0.3 mm. The resolution by using MRI technique is 10 to 100 micrometer. By using the ultrasound sonography. The depth obtained is in a few centimeters and the resolution is 0.1 to 1 mm. The high frequency ultrasound of 50 MHz gives the resolution upto 20 micrometer while the ultrasound with 100 MHz frequency provides the resolution upto 15 to 20 micrometer. The resolution of the computed tomography (CT) scan image is 50 micrometer. By using this OCT technique, we get resolution upto 1 to 15 micrometer while the penetration depth is upto 1 to 3 millimeter.

III. MICHELSON INTERFEROMETER AND SET-UP

The setup of the Michelson Interferometer consists of a broadband laser source, a beam splitter, a sample & a reference arm and a photo-detector. A beam splitter is used in a bulky optical source while a coupler is used in the case of a optical fiber. The light beam gets split by the beam splitter and one ray of light falls on the sample arm while the other

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on the reference arm. Some amount of the incident light is get absorbed and some get reflected from the sample arm. The light reflected from the sample and reference arm return back to the beam splitter and both the waves interferes with each other. So that an interference pattern is formed which is detected at the photo-detector.Then this data of the interference spectrum is processed by using Matlab script, so that we get the A scan image and further the B scan image is formed by using multiple ‘A’ scan data.

IV. CALCULATIONS

A. The thickness can be calculated by using given formula:

$$Thickness\ (t) = \frac{L}{\Delta L} * \frac{\lambda}{2}$$

where, L=Width of darkness of fringes
ΔL= Width of lightness of fringes
λ = Wavelength of the laser source

B. The coherence length is calculated using given formula:

Generally, a broadband source is selected for OCT. Resolution of the image is decided by the coherence length of source. If Tc is the time over which a propagating wave may be considered coherent, then Lc (coherence length) is the distance travelled by the wave in Tc which is coherence time.

$$Lc = c * Tc$$

where, Lc = Coherence length
c = Speed of the light
Tc = Coherence time

Also, $$\text{Coherence length, Lc} = \frac{0.44}{\eta} * \frac{\lambda^2}{\Delta\lambda}$$

where, λ = Centre wavelength of the source
Δλ = Bandwidth of the source
η = Refractive index of the material

C. The penetration depth can calculated using the given formula:

$$Zmax = \frac{\lambda^2}{\Delta\lambda} * \frac{N}{4\eta}$$

where, λ = Centre wavelength of the source
Δλ = Bandwidth of the source
η = Refractive index of the material
N = Pixel number

V. SET-UP ARRANGEMENT

The following figure shows the basic set-up for the Michelson Interferometer:

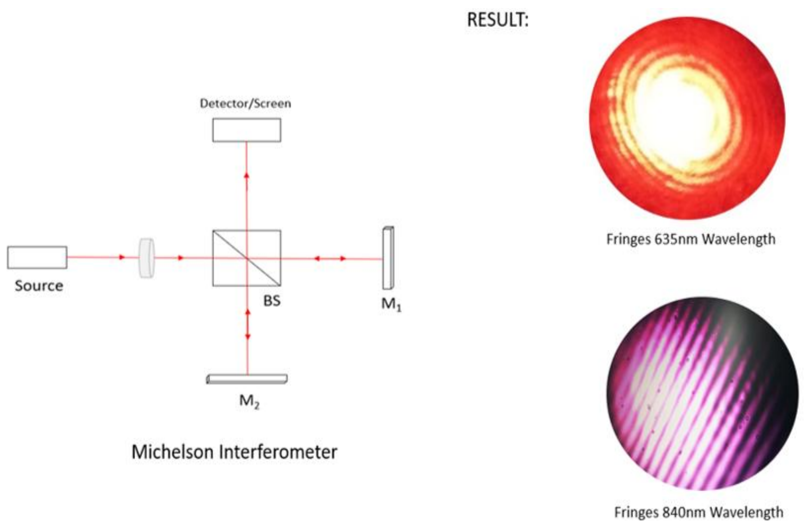

Fig.1. Basic set-up of Michelson Interferometer

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The figure shows the fringes obtained at wavelengths 635 & 840 nm respectively by using the CCD camera. The components used are as: SLD source (635 nm & 840 nm), spectrometer (stellernet & avantes), optical fibers, beam splitter, reflectors, CCD camera, infrared (IR) card, computer, optical bench.
The following figure shows the schematic set-up for A-scan:

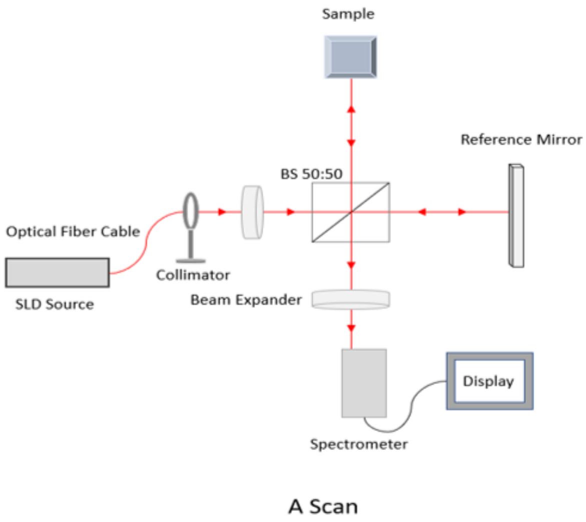

Fig.2. Set-up for A-scan

The following figure shows schematic set-up for B-scan :

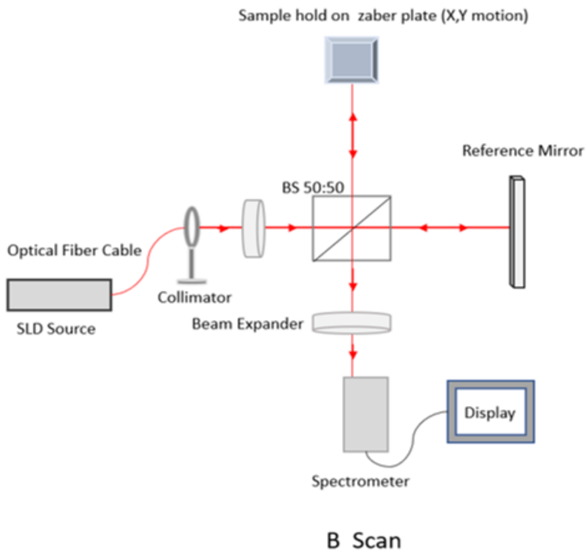

Fig.3. Set-up for B-scan

VI. WORKING AND SIGNAL PROCESSING

The current at the detector is given as,

$$\begin{aligned} I_D(k) = & \frac{\varrho}{4}[S(k)[R_R + R_{S1} + R_{S2} + \ldots]] \\ & + \frac{\varrho}{2}[S(k)\sum_{n=1}^{N} \sqrt{R_R R_{Sn}} \cos[2k(Z_R - Z_{Sn})]] \\ & + \frac{\varrho}{4}[S(k) \sum_{n \neq m=1}^{N} \sqrt{R_{Sn} R_{Sm}} \cos[2k(Z_{Sn} - Z_{Sm})]] \end{aligned}$$

where,
$R_{S1}, R_{S2}, ..$= Reflectivity of each sample
$Z_{S1}, Z_{S2}, ...$= Physical distances of each sample
ϱ = Responsivity of the detector.

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This equation contains three terms as: DC component term, cross-correlation & auto-correlation term respectively. The DC term is called as direct component term and it contains only power reflectivities of reference and sample. The second term is a cross-correlation term which is the desired term for OCT. It contains the OCT information. It depends on the path length difference between the reference arm and sample. The third term is the auto-correlation term which represents the interference occurring between the different layers of the same sample. Generally, it depends on the power reflectivity of the sample. The signal processing chain includes varios steps like background subtraction, noise reduction, resampling, dispersion compensation, fast fourier transform, magnitude compensation and the compression. The reference spectrum is detected and subtracted from the interference spectrum to eliminate the reference power term. The spectrometer measures the optical intensity as a function of wavelength. So here, we get the data in lambda space. We have to convert it into k-space.The resampling is employed to re-sample the acquired intensities from acquired domain into frequency domain. The linear interpolation technique is used for this purpose.The basic operation to get the depth resolved in A scan is inverse fast fourier transform. Each IFFT creates a particaular A-scan.The IFFT information is double sided in nature, so that we need only single side of the spectrum. By eliminating the dc term and auto-correlation term, we get the final A scan image.The multiple set of A scan makes B scan image.

VII. SIMULATION RESULTS

A. For A scan:

'A' scan image is obtained by scanning the sample at a single position. It provides information about the depth and various layers at that point. The samples used are stack of coverslips and stack of insulation tape. The results are obtained at 635 and 840 nm respectively. The 'a' scan results are as shown below for these samples:

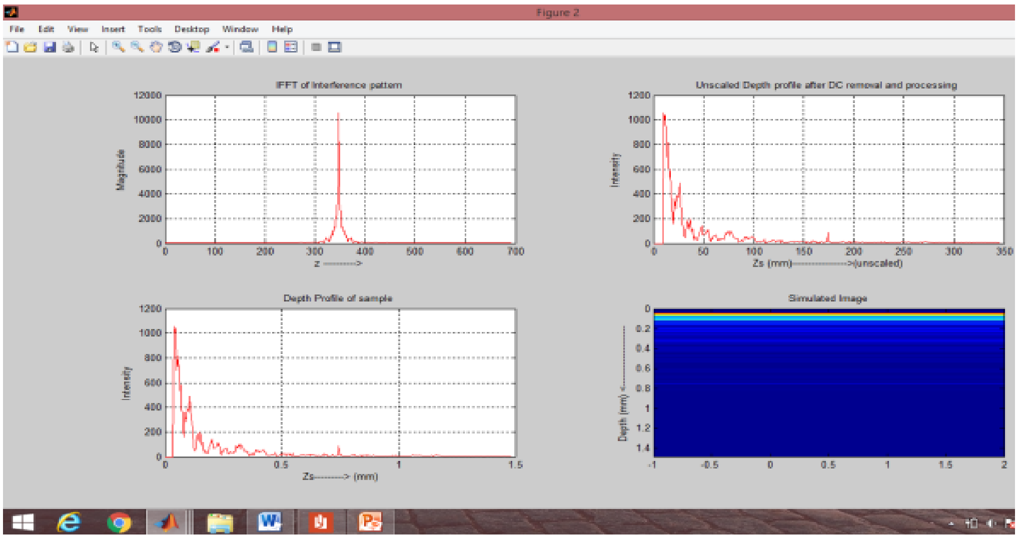

Fig.4. A-scan of stack of coverslip at 635 nm

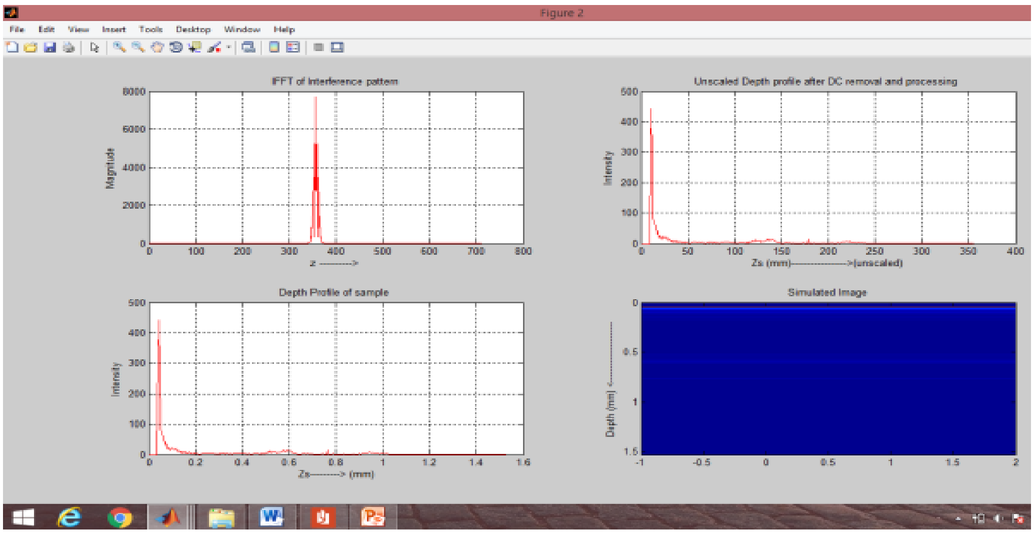

Fig.5. A-scan of stack of coverslip at 840 nm

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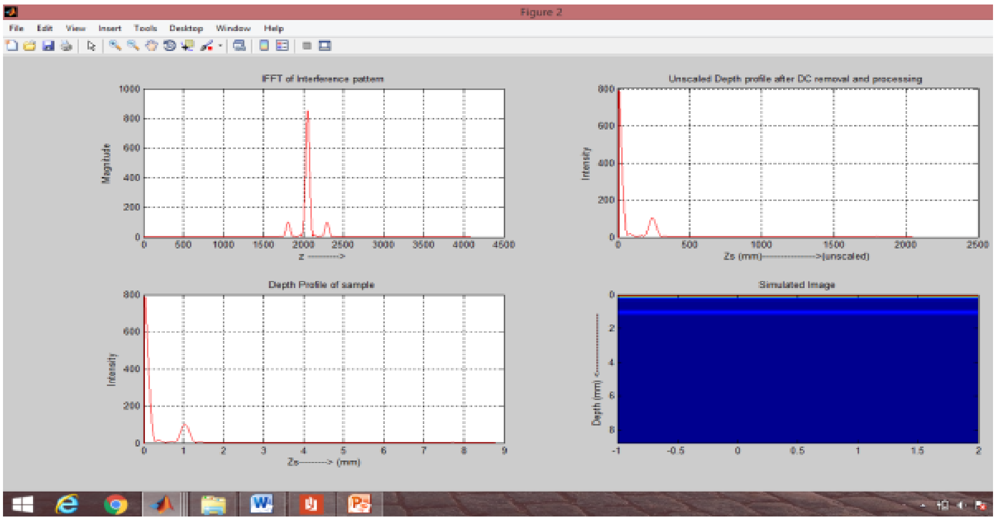

Fig.6. A-scan of stack of insulation tape at 635 nm

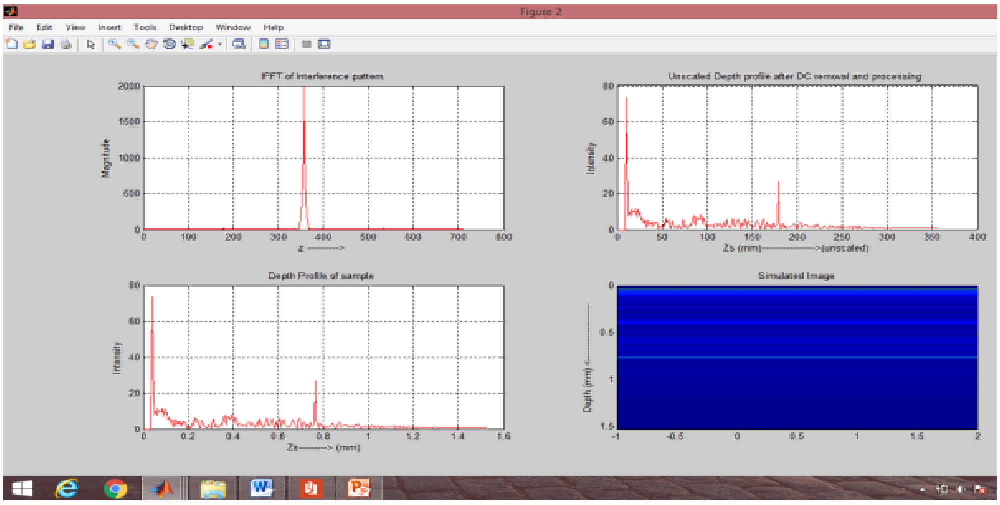

Fig.7. A-scan of stack of insulation tape at 840 nm

B. For B scan:

These are some results for the b scan as shown below:

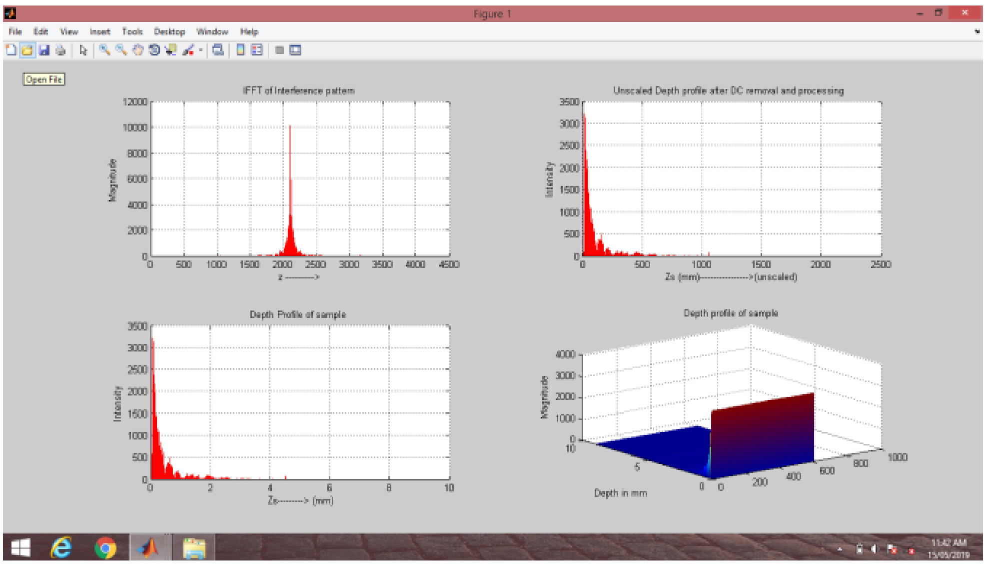

Fig.8. B-scan of stack of coverslip at 635 nm

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B scan image is obtained by scanning the sample in a particular direction, so as to get the information of the depth profile of the entire area. B scan image is a 2D image. To scan the sample, motion stages were used called as a Zaber plate. It scans the sample in x and y direction. The sample used for imaging was stack of coverslip and stack of the insulation tape. This is done at 635 and 840 nm wavelength.

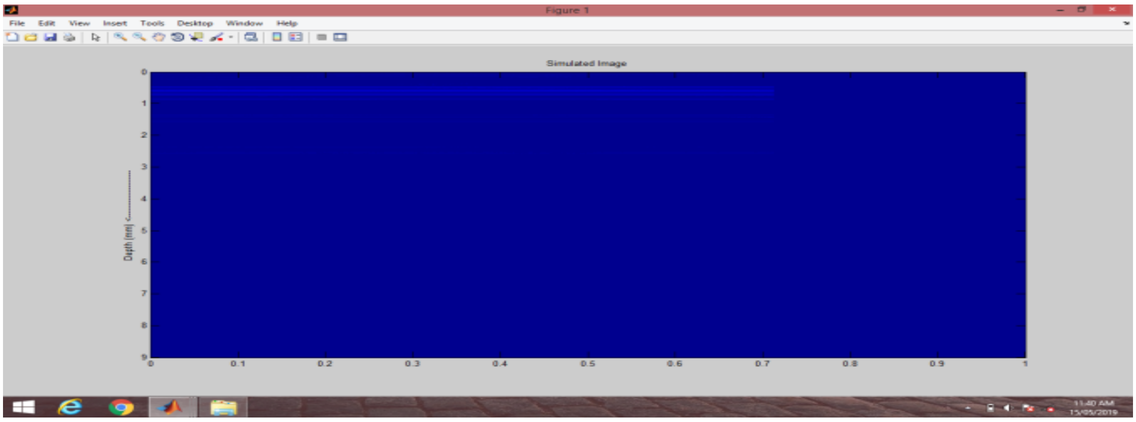

Fig.9. B-scan of stack of coverslip at 635 nm

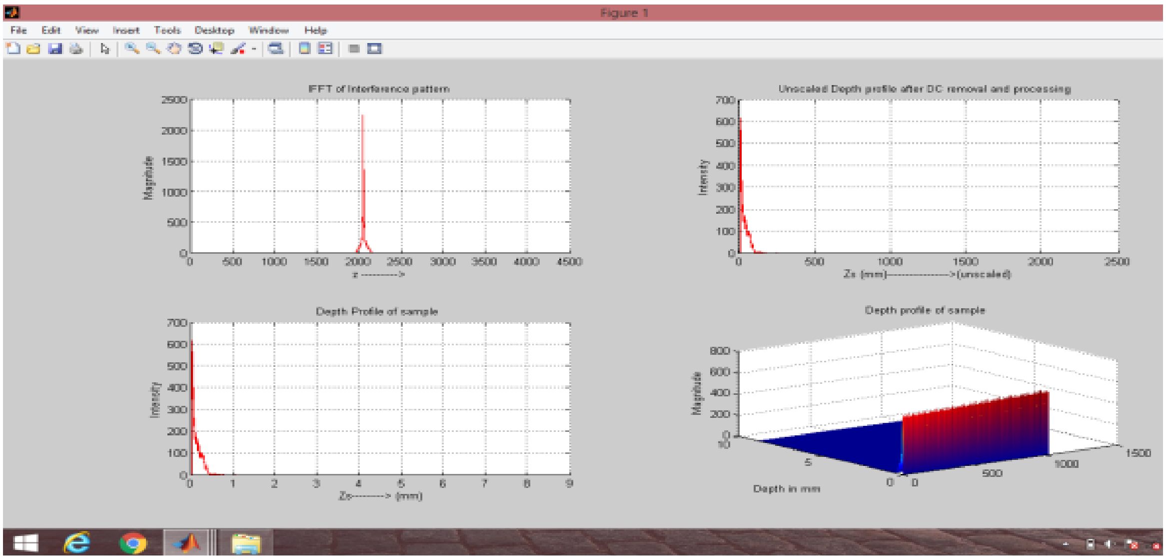

Fig.10. B-scan of stack of coverslip at 840 nm

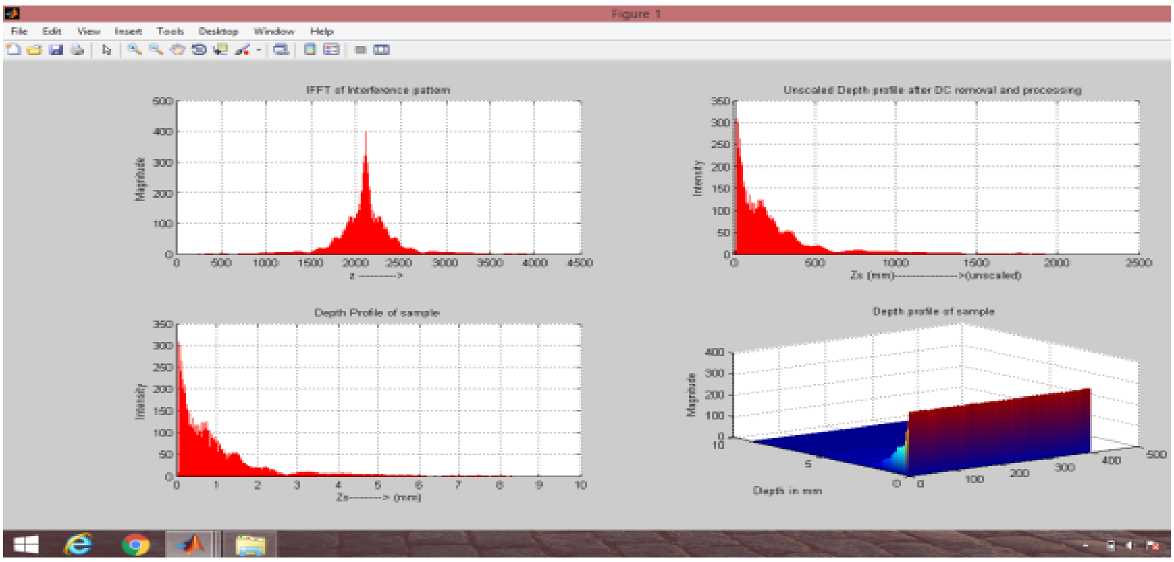

Fig.11. B-scan of stack of insulation tape at 635 nm

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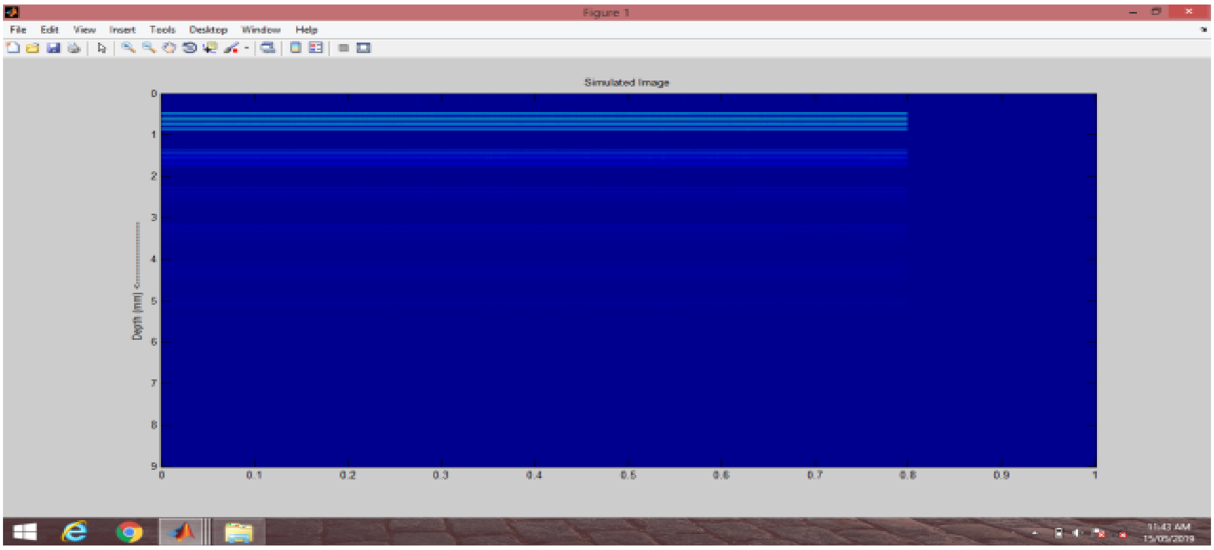

Fig.12. B-scan of stack of insulation tape at 635 nm

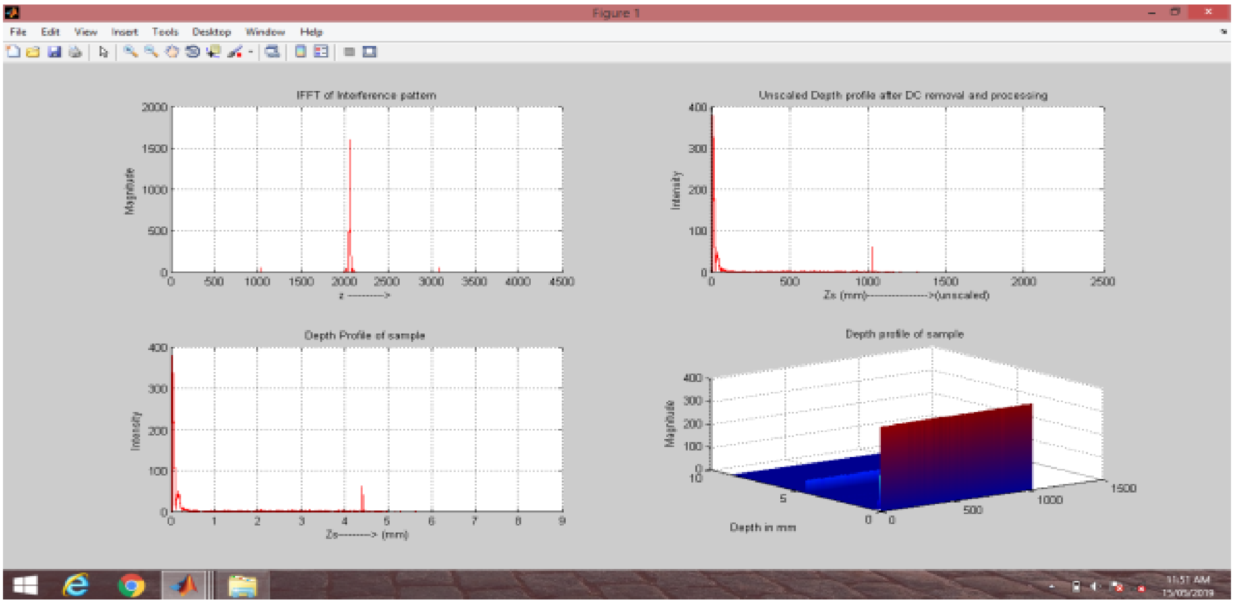

Fig.13. B-scan of stack of insulation tape at 840 nm

VIII. TABULATED RESULTS

Table I: For wavelength 635 nm:

Sample	Axial resolution (micrometer)	Depth (mm)
Stack of coverslip	8.62	4.4
Stack of insulation tape	9.85	4.9

Table II: For wavelength 840 nm:

Sample	Axial resolution (micrometer)	Depth (mm)
Stack of coverslip	5.57	2.88
Stack of insulation tape	6.19	3.2

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IX. CONCLUSION

The optical coherence tomography technique finds its applications in many areas like ophthalmology, dentistry, surgical guidance, dermatology, cancer diagnosis, micro layer diagnosis of a biological as well as non-biological object. The signal processing algorithm is done using Matlab. The axial resolution of the samples studied is found to be better at the wavelength of 840 nm as compared to the values at the wavelength of 635 nm. However, the maximum penetration depth was found to be higher at 635 nm as compared to the values at 840 nm. The scanning mechanism can be improved further at these wavelengths by employing circulators in the B-scan setup.

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BIOGRAPHIES

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Dr. S. L. Nalbalwar has done his Ph.D. in E&TC from IIT Delhi. Currently, he is working as professor & head of the department of Electronics & Telecommunication Engineering at Dr. Babasaheb Ambedkar Technological University, Lonere, Raigad. His area of interest includes signal processing. He has various publications which includes 100 internantional journals, 50 national journals, 70 international conferences and 50 national conferences. He has also published books in signals & systems, basic electronics and electronics devices and circuits.

Dr. Roshan Makkar has completed his Ph.D in biomedical engineering from IIT Bombay. Currently, he is working as a scientist at SAMEER in photonics division, IIT-B campus, Mumbai. He has been investigator for several R&D projects in design and development of various integrated optical devices and polymer waveguide based biosensors in SAMEER. He has also guided several M. Tech dissertations.