

**OPTICAL INTERFEROMETRIC STUDIES OF  
NEMATIC LIQUID CRYSTAL MATERIALS AND  
THEIR APPLICATIONS**

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**INSTRUMENT DESIGN DEVELOPMENT CENTRE**

**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**FEBRUARY 2015**

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NEMATIC LIQUID CRYSTAL MATERIALS AND  
THEIR APPLICATIONS**

by

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**INSTRUMENT DESIGN DEVELOPMENT CENTRE**

Submitted

*in fulfillment of the requirements of the degree of*

*Doctor of Philosophy*

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**FEBRUARY 2015**

# CERTIFICATE

This is to certify that the thesis entitled “**OPTICAL INTERFEROMETRIC STUDIES OF NEMATIC LIQUID CRYSTAL MATERIALS AND THEIR APPLICATIONS**” is being submitted by **MR. MOHAMMAD INAM** to the **Instrument Design Development Center, Indian Institute of Technology Delhi** for the award of the degree of **DOCTOR OF PHILOSOPHY**. This thesis is a record of bona-fide work carried out by him under my guidance and supervision. In my opinion the thesis has reached the standards fulfilling the requirements for submission relating to the degree. The results contained in this thesis have not been submitted to any other University/Institute for the award of any degree or diploma.

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## ACKNOWLEDGEMENTS

Countless people have supported me throughout the journey of my Ph.D.. I would most like to express my sincere gratitude to my advisor Prof. D. S. Mehta, who, in my eyes, is the very definition of a mentor. His guidance helped me all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Ph.D. study.

I would like to thank the other members of my committee, Prof. A. L. Vyas, Dr. Gufran S. Khan and Prof. P. Senthilkumaran for the assistance they provided at all levels of the research project.

I thank to Dr. A. M. Biradar (National Physical Laboratory, Delhi) and Dr. Jai Prakash for providing his laboratory facility whenever required and healthy discussion about my research. I would like to thank to Prof. Kanchan Saxena (Amity University, Noida) for her valuable guidance and healthy discussion about my research whenever required. I would like to thank to Prof. Vipin Kumar Tripathi for his valuable and fruitful help whenever I approached to him. I thank to Dr. Vishal Srivastava from the bottom of my heart for his help and moral support going beyond the line during my whole Ph.D. work. I would like to thank Dr. Tulsi Anna, Dr. Ranjeet Kumar and my colleague Gyanendra Singh, Dr. Rakhi Grover, Brijesh Kumar, Tilak Joshi, Dr. Ajay Kumar, Dr. Anu Malik, Azeem Ahamed, Vishesh Dubey and Sonam Berwal for their support and helpful discussion.

I am thankful to technical staff of workshop in IDDC Mr. Rajaram, Mr. Vikas Kumar for designing various components of experimental set-ups.

I am also thankful to my friends Varun Kumar, Manoj Kumar, Dr. Manoj Kumar and Dr. Pawan Kumar, Deepanshu for their moral support and help at various stages of my research tenure.

On a personal note, I would like to thank my parents. Thank you for the everlasting love and support. I know that wherever I am in my life you are always proud of me. I am proud of being your son. Finally, I would like to thank my wife Afsana for her continuous support during my Ph.D. This could not have been done without her strength and motivation.

I will miss every moment, I spent at IIT Delhi and I wish my learning can be used for something good.

(Mohammad Inam)

## ABSTRACT

The liquid crystal cell parameters such as tilt angle, birefringence (also called as double refraction), retardation (the cell gap times the LC birefringence), dielectric anisotropy, and switching voltage are important in the manufacturing as well as the development of LCD. There is constant need for an accurate measurement of these cell parameters, effect of metallic nanoparticles on electro-optical properties, and applications of LC cell as a phase modulator, since LC material has voltage dependent birefringence.

This thesis presents the optical interferometric techniques to measure the liquid crystal cell parameters using Fourier transform fringe analysis. Using the optical interferometric technique wavelength dependent birefringence of liquid crystal material has been determined, and for this, a nearly common path Mach-Zehnder interferometer has been developed. Also, the effect of gold nano-particles on electro-optical properties of liquid crystal material has been presented. A liquid crystal (LC) phase shifting interferometer was developed for generating voltage dependent phase shifting interferograms. Liquid crystal filled cell has been used as a phase modulator for the 3-D shape measurement of a reflecting object and simultaneously quantitative phase imaging of a transparent object.

The technique for the measurement of LC cell parameters using optical interferometry has been covered in various chapters in the present thesis, and the application of nematic liquid crystal material filled cell in 3-D Profilometry of an object in reflection mode as well in transmission mode have also been covered in two separate chapters.

**Chapter I** presents the literature survey about LC materials and their some physical properties. Introduction about various important LC cell parameters, which affects the LC based display devices and other applications of LC materials have been discussed. In this chapter, various

techniques for the measurement of LC cell parameters have been reviewed. The effect of metallic nano-particles, nano-rods, and carbon nano-tubes on electro-optical properties of LC materials has also been mentioned. The literature survey about various techniques for 3-D Profilometry, including that of phase shifting interferometry has been presented.

**Chapter II** In this chapter, a wide field optical technique for the measurement of nematic liquid crystal (NLC) cell parameters i.e., switching voltage, birefringence, retardation, dielectric anisotropy, average tilt angle and change in refractive index with applied dc voltage to LC material is presented. The proposed method is based on optical interferometry and Fourier transform fringe analysis technique in which we obtain 2-dimensional (2D) phase map of the interferograms as a function of applied voltage. Mach-Zehnder interferometer (MZI) was used for the study of cell parameters and interferograms were recorded at different applied dc voltages to NLC cell using CCD camera. From the 2-D phase map, 2D-refractive index distribution of the LC cell with applied voltage was reconstructed. Analytical equations are derived based on optical interferometry and then solved to obtain cell parameters. The present method is wide field, fast and can give 2D-cell parameters from only two quick interferograms.

**Chapter III** presents the measurement of birefringence of nematic LC material using multiple wavelength interferometry. Nearly common path single-stage Mach-Zehnder interferometer was developed and used for recording interferograms. Fourier transform fringe analysis was used for reconstructing the 2-D phase map. Change in phase as a function of applied voltage to liquid-crystal cell was measured for blue, green and red color laser light remaining the temperature constant during the experiment. From the change in phase, the birefringence of LC material for three colors i.e. red, green and blue was measured. It was found that the birefringence of nematic liquid crystal (ZLI-4155) material for red, green and blue colors decreases with increase in

wavelength. The decrease in birefringence for the wavelength increase from the blue to red color is about 40%.

**In Chapter IV** we describe the observation of large changes in the electro-optical properties of nematic liquid crystal (NLC) due to inclusion of small concentration of 10 nm diameter gold nanoparticles (GNPs). It is observed that GNPs lower switch-on voltage and also lower relaxation frequency with applied voltage (AC field) to NLC cell. All these studies have been done by optical interferometry and capacity measurement by impedance analyzer of a NLC cell. The change in threshold voltage and relaxation frequency by doping GNPs in NLC is explained theoretically.

**In Chapter V** we present the development of a common-path and non-mechanical scanning phase-shifting lateral shearing interferometer based on homogeneous and wedge-shaped gap liquid-crystal cell. The modified cell consists of semi-reflecting and fully-reflecting glass plates with liquid-crystal material sandwiched between them so that the amount of reflected light from both the surfaces is nearly equal, thus generating high contrast interference fringes. The thickness of liquid-crystal cell was maintained  $\sim 3 \mu\text{m}$  uniformly for homogeneous gap and varying wedge gap was also introduced between two glass plates for generating high carrier frequency linear fringes. Phase-shifting linear fringe patterns of high contrast were generated. The phase shifted interferograms were projected onto an object and the distorted interferograms were recorded by CCD camera. Phase shifting fringe analysis technique was used to reconstruct the 3-D shape of the object. Present system is compact and low cost.

**Chapter VI** presents the use of nematic liquid crystal filled cell as a phase modulator for 3-D profilometry of microlenses. In one arm of Mach-Zehnder interferometer nematic liquid crystal filled cell with DC voltage connection was placed for modulating the phase and in another arm

of the interferometer micro-lenses with 4-F imaging system has been placed. Interference takes place between the lights coming from the two arms of the Mach-Zehnder interferometer, one after passing through nematic liquid crystal cell and another after passing through micro-lenses were recorded by CCD camera. By applying voltage to liquid crystal cell various phase shifted inteferograms were recorded and from phase shifted interferograms, shape and size of micro-lenses were determined.

**In Chapter VII** we summarize the entire work done and also report the future work scope of the present work.

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