OPTICAL INTERFEROMETRIC AND SPECTROSCOPIC STUDIES OF FLEXIBLE PET SUBSTRATE AND ITS APPLICATIONS

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INSTRUMENT DESIGN DEVELOPMENT CENTRE

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

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Submitted

to the fulfillment of the requirements of the degree of

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Dedicated to

My Grandparents

CERTIFICATE

This is to certify that the thesis entitled ***'OPTICAL INTERFEROMETRIC AND SPECTROSCOPIC STUDIES OF FLEXIBLE PET SUBSTRATE AND ITS APPLICATIONS'*** being submitted by **MR. GYANENDRA SINGH** (2009IDZ8220) to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy**, is a record original bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis. The results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Organic and polymeric semiconductors are replacing their inorganic counterparts due to their various advantages like, large area application, ease of fabrication, mechanically flexible, light weight, good electrical and optical properties. The fabrication of semiconductor devices based on these materials is generally solution processed or thermally evaporated. The branch of electronics that deals with this solution processed materials is known as "flexible electronics and photonics". Flexible displays are the need of the future as it has much attraction attached to it which is a good alternative for existing technology. These displays are portable as they can be rolled and folded. Commercially available flexible displays are still not available in the market, but it is estimated that within next few years they will become part of our daily life. In future, flexible electronics will change human interaction with the technology. Most of the organic and polymeric semiconductor devices are fabricated on a transparent conducting flexible substrate. These substrates can be easily prepared and roll-to-roll processed which is good for the economical point of view. The demand for the large area electronics is increasing with its application in the various field such as display, sensors, e-paper, textile and medical imaging.

Generally the indium tin oxide (ITO) coated polyethylene terephthalate (PET) substrates are used for making the flexible photonics and display devices. But the ITO layer is brittle in nature which cracks on bending and the conductivity of the device will change. Semi crystalline PET is widely used as substrate for the flexible electronics and photonics because they have the high transparency, mechanical strength and solvent resistant nature. The fabrication process of the PET substrate leads to the generation of optical birefringence due to residual stress. The birefringence values changes with the external applied stress while

bending the substrate. Therefore, the optical properties of the device fabricated on these substrates will change due to residual stress and bending induced birefringence. Hence it is important to study the optical properties, i.e., wavelength dependent birefringence, state of polarization and spectrum profile of these flexible substrates as a function of external applied stress along with the residual stress. In this thesis we describe the experimental results of the measurement of these properties using optical interferometry and spectroscopy of flexible PET substrate and demonstrate some of its applications.

The thesis is started with the general introduction of the field and the evolution of the flexible electronics. The basic components of the flexible electronics are discussed and more emphasis is given to the substrate material. Measurement of the birefringence as well as residual stress of the commercially available flexible substrate on bending using the photo-elasticity and Mach-Zehnder interferometry (MZI) along with the digital fringe analysis is discussed in chapter 2 and 3. From these techniques the 2-D phase information of the light passing through the PET substrate can be obtained. The polarization study of the PET substrate is done using polarizing interferometer and results are presented in chapter 4. It was found that the SOP of the light transmitted through the PET substrate changes drastically. Spectral measurement for the light transmitted through the PET substrate for different wavelength LEDs and halogen source is presented in chapter 5 using the photo elasticity set-up and spectrometer. Spectrum profile for the light of different wavelength passing through the PET substrate changes along with the spectral modulation in the broadband source. Chapter 6 and 7 presents the application of the PET substrate as a flexible diffuser for designing the new white light source based on organic and inorganic phosphor and blue LED. In the last chapter 8, work presented in the thesis is concluded along with the future scope of work.

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ABBREVIATIONS

SSL	Solid State Lighting
LED	Light Emitting Diode
SC	Semiconductor
OLEDs	Organic Light Emitting Diodes
HOMO	Highest Occupied Molecular Orbital
LUMO	Lowest Unoccupied Molecular Orbital
ICs	Integrated Circuits
TFT	Thin Film Transistor
AMLCD	Active Matrix Liquid Crystal Display
LC	Liquid Crystal
CRT	Cathode Ray Tube
Tm	Maximum Temperature
Tg	Glass Transition Temperature
CTE	Coefficient Of Thermal Expansion
PC	Polycarbonate
PI	Polyimide

PAR	Polyarylate
PES	Polyethersulphone
PCO	Polycyclic Olefine
PET	Polyethylene Terephthalate
PEN	Polyethylene Naphthalene
PEEK	Polyether-Etherketone
PLEDs	Polymer Based Light Emitting Diodes
AMOLEDs	Active Matrix Organic Light Emitting Diodes
FOLEDs	Flexible Organic Light Emitting Diodes
UV	Ultraviolet
OTFT	Organic Thin Film Transistor
PV	Photovoltaic
CCD	Charged Coupled Device
MZI	Mach-Zehnder Interferometer
FTF	Fourier Transform Fringe
SOP	State Of Polarization
ITO	Indium Tin Oxide
ITO/PET	Indium Tin Oxide Coated Polyethylene Terephthalate

RGB	Red, Green And Blue
CIE	Commission Internationale De l'Eclairage
CRI	Color Rendering Index
CCT	Correlated Color Temperature
Znq_2	Zinc(II)Bis(8-Hydroxyquinoline)
([Ir(MDQ)$_2$(acac)]	Iridium(III)Bis(2-Methyldibenzo-[F, H] Quinoxaline) (Acetylacetonate)
YAG: Ce	Cerium Doped Yttrium Aluminium Garnet
iPP	Isotactic Polypropylene
Δn_{ind}	Induced Birefringence
Δn_{res}	Residual Birefringence
PEM	Photoelastic Modulator
QWP	Quarter Waveplate
DOP	Degree Of Polarization
HWP	Half Wave Plate
BS	Beamsplitter
PBS	Polarizing Beam Splitter
M	Mirror
CL	Collimating Lens

BE	Beam Expander
ROC	Radius Of Curvature
EL	Electroluminescent
PMMA	Poly-Methyl Methacrylate
Y(Gd)AG:Ce	Cerium-Doped Yttrium-Gadolinium Aluminum Garnet
GaInN	Gallium Indium Nitride
PL	Photoluminescence
WLEDs	White Light Emitting Diodes
FWHM	Full Width Half Maximum
PVAc	Polyvinyl Acetate
SEM	Scanning Electron Microscope