

CONTROLLING THE SPECTRAL AND POLARIZATION PROPERTIES OF LIGHT FIELDS USING NEMATIC LIQUID CRYSTAL

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CONTROLLING THE SPECTRAL AND POLARIZATION PROPERTIES OF LIGHT FIELDS USING NEMATIC LIQUID CRYSTAL

by

GYAPRASAD

Department of Physics

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY
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Dedicated to My Parents and Teachers

Certificate

This is to certify that the thesis entitled “**Controlling the spectral and polarization properties of light fields using nematic liquid crystal**”, submitted by **Gyaprasad** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** in Physics, is a record of the original, bona fide research work carried out by him under my supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

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Abstract

In this thesis, we explore both theoretically and experimentally the modification and manipulation of spectral and polarization properties of light using electro-optically controlled nematic liquid crystal (NLC). NLCs are significant due to their fast response to applied electric fields and their ability to control the light polarization make them essential in various technologies. First, we show the shaping of the broadband spectrum of light passing through NLC with the help of manually controlled polarizers. The different shapes of broadband spectra have many applications for making spectral filters, designing optical sources of various coherence lengths, metrology, etc. Secondly, we demonstrate the shaping of spectra by electro-optically controlled NLC which provides us with a fast response. Electro-optically controlled shapes of light spectra are used for designing the tunable optical frequency ruler and an optical switch is demonstrated. A free-space optical communication scheme is also proposed using the spectral switch. Further, We focus on controlling the polarization properties of light fields, such as the degree of polarization (DOP) and the state of polarization (SOP). We manipulate the polarization attributes of light using electro-optically controlled NLC. A variable DOP in reflected light is achieved when an unpolarized light is incident on electro-optically controlled NLC at Brewster's angle. It is also demonstrated that the SOP in reflected light can be tuned when a polarized light is incident on an electro-optically controlled NLC. This tunability of DOP and SOP is found to be in good agreement with the experiment. DOP of partially coherent fully polarized light decreases or fades as it propagates via birefringent media. NLC materials naturally have large birefringence so the retardation length is large. This property can be utilized to fade the DOP for an even smaller value. In this study, NLC is used as birefringent media for DOP fading which provides us with the tunability in birefringence with respect to the applied voltage. This is a novel method to tune polarization with the help of an electro-optically controlled NLC cell. In the present study, we examine how the SOP varies in response to changes in the DOP, and how both of these parameters can be controlled by applying voltage. This investigation delves into the intricate relationship between these polarization properties and the influence of external voltage, providing valuable insights for applications in the field of optics and developing optical devices.

सार

इस शोध प्रबंध में, हमने, इलेक्ट्रो-ऑप्टिकली नियंत्रित नेमैटिक तरल-क्रिस्टल (एन एल सी) का उपयोग करके, सिद्धांतिक और प्रयोगात्मक रूप से प्रकाश की स्पेक्ट्रल एवं ध्रुवणता से सम्बंधित गुणों की संशोधन और परिचलन की विवेचना की है। एन एल सी इसलिए महत्वपूर्ण हैं क्योंकि इन पर लागू किए गए विद्युत क्षेत्र के कारण इनकी त्वरित प्रतिक्रिया और प्रकाश के ध्रुवण को नियंत्रित करने की क्षमता के कारण इन्हें विभिन्न प्रौद्योगिकियों में आवश्यक रूप से उपयोगी बनाती है। सर्वप्रथम, हमने नियंत्रित पोलाराइज़र्स की मदद से एन एल सी के माध्यम से गुजरने वाले प्रकाश के ब्रॉडबैंड स्पेक्ट्रम को विभिन्न आकारों में परिवर्तित करने का प्रदर्शन किया है। विभिन्न आकारों वाले ब्रॉडबैंड स्पेक्ट्रम के कई अनुप्रयोग होते हैं, जैसे कि स्पेक्ट्रल फ़िल्टर बनाने में, अनुप्रयोगों के लिए अलग-अलग सम्बद्धता वाले प्रकाशीय श्रोतों को बनाने में, मापिकी विज्ञान आदि में। द्वितीय, हम विद्युत-प्रकाशीय नियंत्रित एन एल सी द्वारा स्पेक्ट्रम को बदलते हैं जो हमें एक तेज प्रतिक्रिया प्रदान करता है। विद्युत-प्रकाशीय नियंत्रित प्रकाश के स्पेक्ट्रम के रूपों का उपयोग परिवर्तनीय ऑप्टिकल फ्रीक्वेंसी रूलर की रचना करने के लिए किया जाता है एवं इनका एक ऑप्टिकल स्विच के रूप में उपयोग प्रदर्शित किया जाता है। स्पेक्ट्रल स्विच का उपयोग करते हुए एक स्वतंत्र-अंतरिक्ष प्रकाशीय संवाद (संचरण) योजना भी प्रस्तुत की जाती है। इसके अलावा, हम प्रकाश क्षेत्रों की ध्रुवणता के गुणों को नियंत्रित करने पर केंद्रित करते हैं, जैसे कि ध्रुवणता की मात्रा (डी ओ पी) और ध्रुवणता का प्रकार (एस ओ पी)। हम विद्युत-प्रकाशीय नियंत्रित एन एल सी का उपयोग करके प्रकाश की ध्रुवणता के गुणों को परिवर्तित करते हैं। यदि एक अध्रुवित प्रकाश विद्युत-प्रकाशीय नियंत्रित एन एल सी पर ब्रूस्टर कोण पर आपतित होता है, तो प्रकाश के लिए एक परिवर्तनीय डी ओ पी हासिल की जाती है। यह भी प्रदर्शित किया गया है कि प्रकाश विद्युत-प्रकाशीय नियंत्रित एन एल सी पर आपतित समतल ध्रुवित प्रकाश की एस ओ पी को भी बदला जा सकता है। यह डी ओ पी और एस ओ पी की इस विवर्तनीयता को प्रयुक्त प्रयोग के साथ सही पाया गया है। जब प्रकाश एक एकाक्षीय माध्यम से संचारित होता है तो इसकी आंशिक सम्बद्धता एवं पूर्ण ध्रुवित प्रकाश की ध्रुवणता की मात्रा समाप्त अथवा फीकी हो जाती है। एन एल सी स्वाभाविक रूप से अधिक द्विअपवर्तन वाले माध्यम होते हैं, इसलिए कालांतर अथवा विलंब-स्थिति बड़ी होती है। इस गुण का उपयोग डी ओ पी को अत्यधिक छोटे मूल्य तक फीका करने के लिए किया जा सकता है। इस अध्ययन में, डी ओ पी को कम करने के लिए एन एल सी को द्विअपवर्तक माध्यम के रूप में उपयोग किया जाता है, जिससे द्विअपवर्तनांक लागू किए गए विभव के सापेक्ष बदलता है। प्रकाश विद्युत-प्रकाशीय नियंत्रित एन एल सी सेल की सहायता से प्रकाश के ध्रुवण को बदलना एक नवीन तरीका है। इस अध्ययन में, हम देखते हैं कि डी ओ पी में परिवर्तन के साथ एस ओ पी कैसे बदलता है, और इन दोनों पैरामीटरों को विभव लागू करके कैसे नियंत्रित किया जा सकता है। इस अन्वेषण में इन ध्रुवणता के गुणों एवं बाहरी लागू किये गए विभव के प्रभाव के बीच के जटिल संबंधों में मूल्यवान अंतरदृष्टि प्रदान की जाती है जो प्रकाशिकी के क्षेत्र में विभिन्न यंत्र विकसित करने के लिए उपयोगी है।

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Abbreviations

AC	A lternating C urrent
DOP	D egree of P olarization
DC	D irect C urrent
EO	E lectro O ptical
FWHM	F ull W idth at H alf M axima
FSO	F ree S pace O ptical
HWP	H alf W ave P late
ITO	I ndium T in O xide
LCD	L iquid C rystal D isplay
LC	L iquid C rystal
LED	L ight E mitting D iode
LCP	L eft C ircularly P olarized
NLC	N ematic L iquid C rystal
OFR	O ptical F requency R uler
PD	P hoto D etector
PM	P ower M eter
QWP	Q uarter W ave P late
RCP	R ight C ircularly P olarized
SOP	S tate of P olarization
SPD	S pectral P ower D istribution
SM	S pectro M eter
SW	S pectral W idth
TOFR	T unable O ptical F requency R uler

Symbols

N	Director
Δn	Birefringence
n_e	Extra-ordinary refractive index
n_o	Ordinary refractive index
n_{eff}	Effective refractive index
G	Order parameter
$\theta(V)$	voltage dependent tilt of director
ω	Angular frequency
λ	Wavelength
E	Electric field
k	Wavevector in free space
$I(r)$	Intensity
$S^0(\nu)$	Spectral density
$ \gamma $	Degree of coherence
c	Speed of light in vacuum
J	Polarization matrix
S	Stokes parameters
V	Voltage
V_{th}	Threshold Voltage