COHERENCE INDUCED POLARIZATION AND SPECTRAL STUDIES OF ELECTROMAGNETIC OPTICAL FIELDS

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by

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Submitted

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

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Dedicated to My Loving Parents and Grandparents

Certificate

This is to certify that the thesis entitled **"Coherence induced polarization and spectral studies of electromagnetic optical fields"**, submitted by **Rajneesh Joshi** 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, bonafide 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

This thesis contains theoretical and experimental studies on coherence, polarization, and cross-spectral purity of vector light fields. We first develop and characterize a source having variable degree of polarization (DOP). We derive a mathematical relation that connects DOP, two-time degree of coherence, and the normalized first Stokes parameter (or distinguishability), also experimentally verified it by using a Mach-Zehnder interferometer (MZI). As a result, by using two different techniques (a) by controlling the correlation between orthogonal electric field components having fix value of normalized first Stokes parameters and (b) by changing the normalized first Stokes parameters of beams having uncorrelated orthogonal field components, we achieve the tunable DOP source. Since electromagnetic fields are partially polarized in nature, we theoretically and experimentally determine the temporal electromagnetic degree of coherence, the temporal degree of cross-polarization, and the DOP using the intensity-intensity (fourth order) correlation of a laser and a light emitting diode (LED) source for any value of DOP for these fields. We also study the effect of spectral parameters on the DOP at the back focal plane of 2-f and 4-f lens systems when spectral electromagnetic Gaussian Schell-model beams pass through these lens systems. Further, we investigate the cross-spectral purity (CSP) and strict CSP for stationary and nonstationary electromagnetic (EM) optical fields. First, theoretically, we obtain the properties of cross-spectrally pure EM optical fields if they pass through two similar ground glass diffusers (GGD) moving in opposite directions with identical speeds or rotating in opposite directions with equal angular speeds, and second, we propose a scheme to achieve the conditions of CSP using a single GGD. This study also proves the equality of space-time and space-frequency degrees of cross-polarization for strict CSP. Finally, we obtain the mathematical conditions of CSP and strict CSP for nonstationary vector fields which are now-a-days avaliable using pulsed and modulated lasers. These fundamental studies on coherence, polarization, and CSP are expected to advance the field of statistical optics to a great extent.

सार

यह शोध प्रबंध सदिश प्रकाश क्षेत्रों के साथ संबंधित कला संबद्धता, ध्रुवण और क्रॉस-स्पेक्ट्रल शुद्धता पर आधारित सैद्धांतिक और प्रायोगिक अध्ययनों को सम्बोधित करता है। हम एक स्रोत को विकसित और चिह्नित करते हैं जिसमें परिवर्तनीय ध्रुवण की मात्रा होती है। हम ध्रुवण की मात्रा, दो समय-कला संबद्धता मात्रा, और मानकृत प्रथम स्टोक्स पैरामीटर (या विभेदनशीलता) को जोड़ने वाले गणितीय संबंध को निर्धारित करते हैं, तथा एक मैक-ज़ेन्डर व्यतिकरणमापी का प्रयोग करके प्रयोगात्मक रूप से सत्यापित करते हैं। परिणामस्वरूप, हम दो विभिन्न तकनीकों का उपयोग करके परिवर्तनीय ध्रुवीकरण स्रोत प्राप्त करते हैं: (क) मानकृत प्रथम स्टोक्स पैरामीटर को नियत करके लंबवत विद्युत क्षेत्र घटकों के बीच संबद्ध नियंत्रित करके और (ख) लंबवत विद्युत क्षेत्र घटकों के बीच शून्य संबद्ध रखके मानकृत प्रथम स्टोक्स पैरामीटर को बदलकर। चूंकि, विद्युत चुम्बकीय प्रकाशीय क्षेत्र आंशिक रूप से ध्रुवीकृत होते हैं, हम सैद्धांतिक और प्रायोगिक विधि से ऐसे क्षेत्र के लिए तीव्रता - तीव्रता (चतुर्थ क्रम) संबद्ध का उपयोग करके आवश्यकतानुसार किसी भी ध्रुवण की मात्रा के लिए लेज़र और एलईडी स्रोत के विद्युत चुम्बकीय कला संबद्धता मात्रा, क्रॉस- ध्रुवीकरण मात्रा और ध्रुवीकरण मात्रा निर्धारित करते हैं। हम 2-एफ और 4-एफ लेंस तंत्र के पीछे के फोकस तल पर ध्रुवण की मात्रा पर स्पेक्ट्रल पैरामीटरों के प्रभाव का भी अध्ययन करते हैं जब स्पेक्ट्रल गाउसियन शैल-मॉडल बीम इन लेंस सिस्टम से गुजरती हैं। इसके अलावा, हम स्थिर और अस्थिर विद्युत चुम्बकीय प्रकाशीय क्षेत्र के लिए क्रॉस-स्पेक्ट्रल शुद्धता और सख्त क्रॉस-स्पेक्ट्रल शुद्धता का अध्ययन करते हैं। पहले, सैद्धांतिक रूप से हम संबंधित घर्षित काँच विसारक के माध्यम से गुजरने वाले विद्युत चुम्बकीय प्रकाशीय क्षेत्र की गुणों को प्राप्त करते हैं, जब दो समान घर्षित काँच विसारक विपरीत दिशा में समान वेग के साथ रेखीय गति करते हैं अथवा विपरीत दिशा में एक समान कोणीय वेग से घूर्णन करते हैं । दूसरे, हम एकल घर्षित काँच विसारक का उपयोग करके क्रॉस-स्पेक्ट्रल शुद्धता की शर्तों को प्राप्त करने की एक योजना प्रस्तावित करते हैं। इस अध्ययन में, सख्त क्रॉस-स्पेक्ट्रल शुद्धता के लिए क्रॉस-ध्रुवीकरण की मात्रा के स्थान-समय और स्थान- आवृत्ति के समानता को भी सिद्ध किया गया है। अंत में, हम आजकल उपलब्ध स्पंदित और मॉड्युलेटेड लेज़र का उपयोग करके अस्थायी वेक्टर क्षेत्र के लिए क्रॉस-स्पेक्ट्रल शुद्धता और सख्त क्रॉस-स्पेक्ट्रल शुद्धता की गणितीय शर्तें प्राप्त करते हैं। हमैं विश्वास है कि यह अनुसंधान कला संबद्धता, ध्रुवण एवं क्रॉस-स्पेक्ट्रल शुद्धता का मौलिक अध्ययन सांख्यिकीय प्रकाशिकी के क्षेत्र को एक बड़ी सीमा तक बढ़ाने की क्षमता रखता है।

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Abbreviations

CCD	**C**harge **C**oupled **D**evice
CDMP	**C**omplex **D**egree **o**f **M**utual **P**olarization
CSDF	**C**ross **S**pectral **D**ensity **F**unction
CSDM	**C**ross **S**pectral **D**ensity **M**atrix
CSP	**C**ross **S**pectral **P**urity
DOC	**D**egree **o**f **C**oherence
DOCP	**D**egree **o**f **C**ross **P**olarization
DOP	**D**egree **o**f **P**olarization
EM	**E**lectromagnetic
EMDOC	**E**lectromagnetic **D**egree **o**f **C**oherence
EMGSM	**E**lectromagnetic **G**aussian **S**chell **M**odel
FWHM	**F**ull **W**idth **at** **H**alf **M**aximum
GGD	**G**round **G**lass **D**iffuser
GSM	**G**aussian **S**chell **M**odel
HBT	**H**anbury **B**rown **T**wiss
HWP	**H**alf **W**ave **P**late
I-I	**I**ntensity - **I**ntensity
LED	**L**ight **E**mitting **D**iode
MCF	**M**utual **C**oherence **F**unction
MCM	**M**utual **C**oherence **M**atrix
MZI	**M**ach **Z**ehnder **I**nterferometer
NPBS	**N**on **P**olarizing **B**eam **S**plitter
PBS	**P**olarizing **B**eam **S**plitter
PD	**P**hotodetector
QWP	**Q**uarter **W**ave **P**late
SEMGSM	**S**pectral **E**lectromagnetic **G**aussian **S**chell **M**odel

TDOC	**T**emporal **D**egree **o**f **C**oherence
TDOCP	**T**emporal **D**egree **o**f **C**ross **P**olarization
TEMDOC	**T**emporal **E**lectromagnetic **D**egree **o**f **C**oherence
WFI	**W**aveffront **F**olding **I**nterferometer
WSI	**W**avefront **S**hearing **I**nterferometer

Symbols

ω	Angular frequency
$\gamma(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Complex degree of coherence
$W(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \omega)$	Cross-spectral density function
D	Distinguishability
E	Electric field
$\gamma_\epsilon(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Electromagnetic degree of coherence
$\Psi_n(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Generalized Stokes parameters in space-time domain
$I(\boldsymbol{\rho})$	Intensity
B	Magnetic field
$\Gamma(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Mutual coherence function
$J(\boldsymbol{\rho}, t)$	Polarization matrix
$\mu(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \omega)$	Spectral degree of coherence
$S(\boldsymbol{\rho}, \omega)$	Spectral density
c	Speed of light in vacuum
$\Psi_n(\boldsymbol{\rho}, t)$	Stokes parameters in space-time domain
$S_n(\boldsymbol{\rho}, \omega)$	Stokes parameters in space-frequency domain
$\mu_\epsilon(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \omega)$	Space-frequency electromagnetic degree of coherence
$P(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Space-time degree of cross-polarization
$P(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \omega)$	Space-frequency degree of cross-polarization
$\gamma_j(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Space-time coherence Stokes parameters normalized by corresponding usual Stokes parameters
$\phi_j(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \omega)$	Space-frequency coherence Stokes parameters normalized by corresponding usual Stokes parameters
$\nu_j(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \tau)$	Space-time coherence Stokes parameters normalized by zeroth usual Stokes parameters

$\eta_j(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, \omega)$	Space-frequency Coherence Stokes parameters normalized by zeroth usual Stokes parameters
$\gamma(\tau)$	Temporal degree of coherence
$\gamma_\epsilon(\tau)$	Temporal electromagnetic degree of coherence
$S_n(\tau)$	Time-domain Stokes parameters
$\Psi_n(\tau)$	Two-time Stokes parameters
V	Visibility
λ	Wavelength
k	Wavevector