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SURFACE RELIEF GRATING AND RETARDAGRAPHY:
OPTICAL MANIPULATION OF AZOBENZENE POLYMER FILMS AND ITS APPLICATIONS
OPTICAL FUNCTIONAL DEVICES
USING AZOBNZENE POLYMER FILM

- Photoisomerization
- Surface relief grating
- Retardagrophy: recording of optical polarization and reconstruction of complex amplitude
- Functional devices based on multilayer polymer thin film
PHOTOINDUCED MASS TRANSPORT

- Nanofabrication, photo-mechanical devices

Two beam interference

Photoinduced surface relief (PSR) formation

POLARIZATION DEPENDENT

50 μm

10 μm
MULTIPLE RECORDING GRATINGS

Surface relief grating

Orthogonal grating structure

Hexagonal structure

Blazed grating structure
Relief depth control by electric field

Homogeneous illumination or heating

Heating + electric field applied
Navier-Stokes equation

\[ \rho \frac{Du}{Dt} = - \nabla P + \mu \nabla^2 \mathbf{u} + \mathbf{F} \]

- **Inertial term**
- **Pressure term**
- **Viscous term**
- **Outer force term**

Continuity equation

\[ \frac{\partial \rho}{\partial t} = 0 \]

\( \mathbf{u} \): velocity vector
COMPUTER SIMULATION OF MASS TRANSFER

Nd:YAG Laser (532 nm)

Intensity: 50 mW/cm²

\[ \nabla^2 \mathbf{E} = -k^2 \mathbf{E} \]

\( \mathbf{E} \): Electric Field

\( k \): Wave number

1 μm
SUMMARY IN SURFACE RELIEF GRATING

- Origin of mass transfer: gradient of light intensity, gradient of light pressure, surface tension

- SRG generation is mainly due to electric dipole interaction with outer electric field.
PHOTOINDUCED BIREFRINGENCE

- Optical storage media, polarization controllable devices

Retardography

Optical recording technique for the retardance of a birefringent object
- Liquid crystal spatial light modulator
  - Multivalued phase recording with a single laser beam
  - Large amount information recording
PHOTOTRIGGERED MOLECULAR REORIENTATION

Polarization axis

trans-azobenzene

Absorption

cis-azobenzene

Absorption Relaxation

Absorption
PHOTOINDUCED BIREFRINGENCE

Azobenzene-containing material

Irradiation area

Polarization axis
POLARIZATION HOLOGRAPHY: RECORDING

Signal beam (Right-circular pol.)

Reference beam (Left-circular pol.)

Azobenzene film
POLARIZATION HOLOGRAPHY:
RECONSTRUCTION

Reference beam (Left-circular pol.)

0 order beam (Left-circular pol.)

Polarization hologram

+1 order diffracted beam (Right-circular pol.)
POLARIZATION HOLOGRAPHY: RECONSTRUCTION

-1 order diffracted beam (Left-circular pol.)

Reference beam (Right-circular pol.)

Polarization hologram

0 order beam (Right-circular pol.)
Linear polarization:
\[
\begin{bmatrix} J_x \\ J_y \end{bmatrix} = R(-\alpha) \begin{bmatrix} 1 \\ 0 \end{bmatrix}
\]

Circular basis:
\[
\begin{bmatrix} J_x \\ J_y \end{bmatrix} = \frac{\exp(-i\alpha)}{\sqrt{2}} \begin{bmatrix} 1 \\ i \end{bmatrix} + \frac{\exp(i\alpha)}{\sqrt{2}} \begin{bmatrix} 1 \\ -i \end{bmatrix}
\]

Principal axes:
\[
\begin{bmatrix} J_x \\ J_y \end{bmatrix} = R(\theta) \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}
\]

Right-circular pol.:
\[
\begin{bmatrix} J_r \\ J_l \end{bmatrix} = \begin{bmatrix} \exp(-i\alpha) \\ \exp(i\alpha) \end{bmatrix}
\]

Left-circular pol.:
\[
\begin{bmatrix} J_r \\ J_l \end{bmatrix} = \exp\left(-i\frac{\Phi}{2}\right) \begin{bmatrix} \exp(i\Phi) \\ 1 \end{bmatrix}
\]

Photoinduced birefringence:
\[
M = R(-\alpha) \begin{bmatrix} \exp(i\Delta\phi/2) & 0 \\ 0 & \exp(-i\Delta\phi/2) \end{bmatrix} R(\alpha)
\]

\[\Delta\phi : \text{Retardance of photoinduced birefringence}\]
PRINCIPLE OF RECONSTRUCTION

Transmission matrix of polarization hologram
\[ M_{rl} = \cos \left( \frac{\Delta \phi}{2} \right) \begin{bmatrix} 1 \\ \frac{\tan(\Delta \phi/2)}{\cos(\Delta \phi/2)} \exp(-i\phi) \end{bmatrix} \]

By left-circular pol.
\[ M_{rl} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{\sin(\Delta \phi/2)}{\cos(\Delta \phi/2)} \exp(i\phi) \\ 1 \end{bmatrix} \]

By right-circular pol.
\[ M_{rl} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} \cos(\Delta \phi/2) \\ \frac{\sin(\Delta \phi/2)}{\cos(\Delta \phi/2)} \exp(-i\phi) \end{bmatrix} \]

Diffraction efficiency
\[ \sin^2(\Delta \phi/2) \]

\[ \Delta \phi : \text{Retardance of photoinduced birefringence} \]

Example of diffraction efficiency

Graph showing diffraction efficiency vs. exposure (J) with a linear region.
PRINCIPLE OF RETARDAGRAPHY

45 degree-linear polarization

Recording laser

x-component
y-component
PRINCIPLE OF RETARDAGRAPHY

Elliptical polarization

Phase difference (Polarization retardance)

Recording laser

x-component
y-component
EXPERIMENTAL SETUP

- **Diode laser (407 nm)**
- **He-Ne Laser (632.8 nm)**
- **HWP**
- **QWP**
- **M**
- **DM**
- **SLM (Birefringent object)**
- **Azobenzene film**
- **HWP: half-wave plate**
- **QWP: quarter-wave plate**
- **M: Mirror**
- **DM: Dichroic mirror**
- **SCF: Color filter**
- **P: Polarizer**
- **SLM: Spatial light modulator**

Recording time: 1 min.
Recording Power: 8 mW
OPTICAL RECORDING
BY RATARDAGRAPHY
SUMMARY IN RETARDAGRAPHY

- Explanation of polarization holographic characteristics in photoinduced birefringent films
  - Complex amplitude of signal beam from an object
    - Amplitude: Retardance of photoinduced birefringence
    - Phase: Principal axis of photoinduced birefringence

- Application to phase-type optical recording by retardagraphy
  - Features of retardagraphy
    - Recording absolute retardance values using a single laser beam
    - High robustness
MULTILAYER STRUCTURE
BY SIPN COATING

Functional photo material:
   Azobenzene polymers

Photoisomerization

Surface relief grating: holography & functional gratings

Photo-induced biphergence: retardagraphy, optical memory & polarization devices
   (polarization grating for LS devices)

Optical multi-layer structure: functional modulator

Collaboration: Joensuu University (Design of functional devices)