Emerging Trends in Research on Sculptured Thin Films

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Thanks

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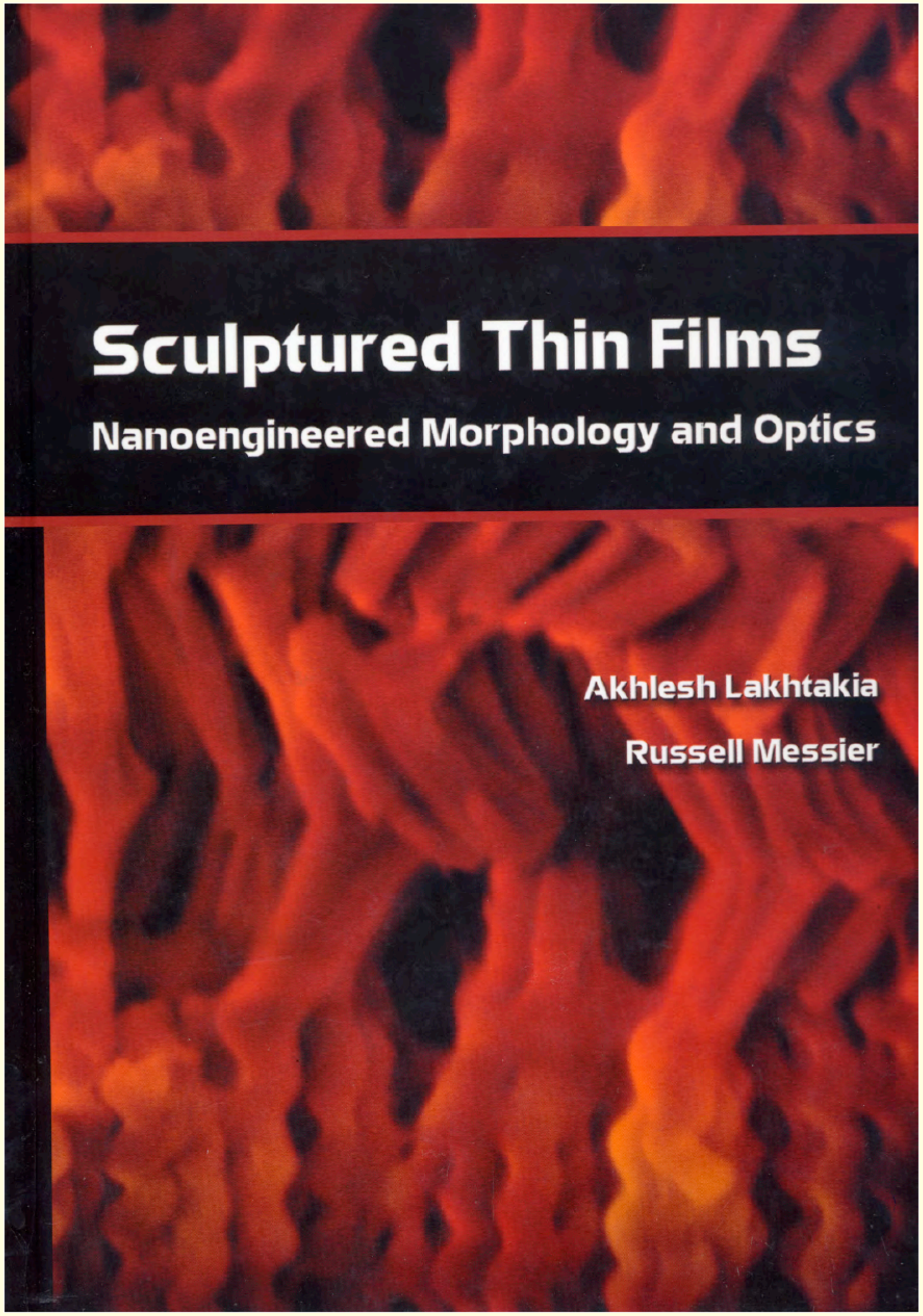
- J. Adrian Reyes (IF, UNAM)

Outline

- Introduction
- Optical Applications
- Optical Modeling
- Emerging Directions
  - Light Emitters
  - STFs with Gain
  - Electrically Controlled STFs
  - Polymeric STFs
  - Bioscaffolds
  - STFs with Transverse Architecture

INTRODUCTION

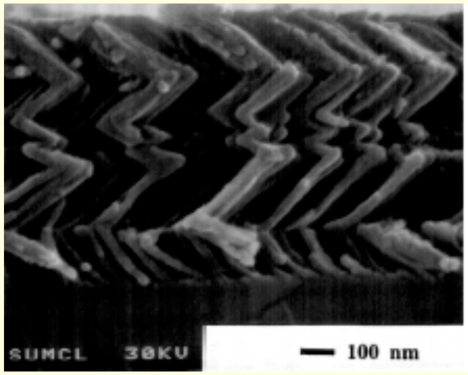


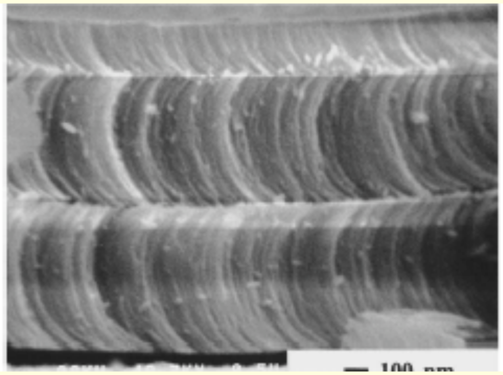
SPIE Press
(2005)

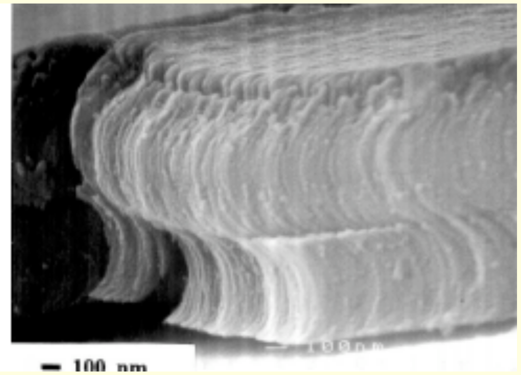
Sculptured Thin Films

Assemblies of Parallel Curved Nanowires/Submicronwires

Controllable Nanowire Shape


SUMCL 30KV
100 nm

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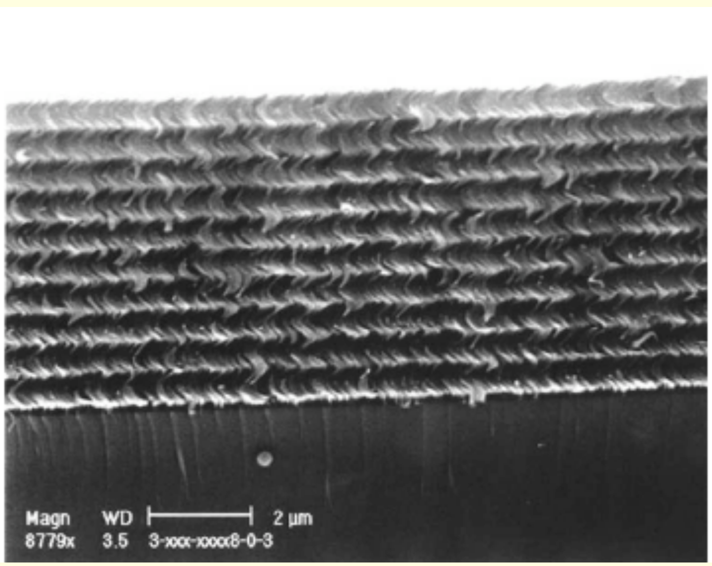
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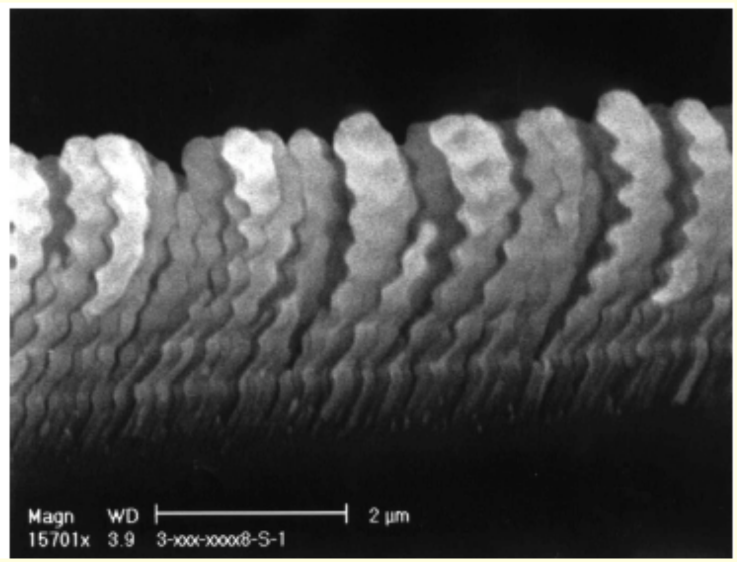
8779x 3.5 3-xxx-xxxx8-0-3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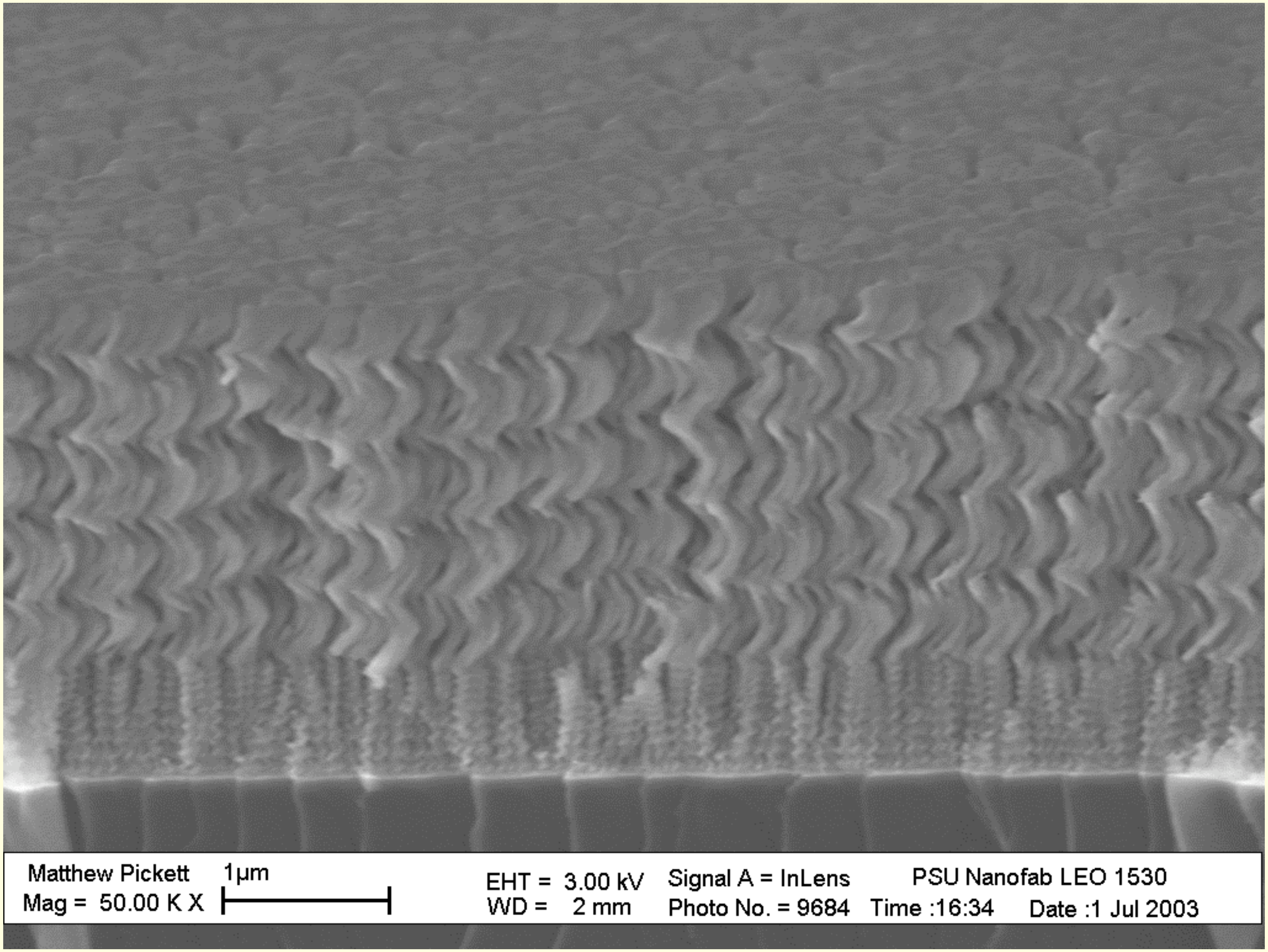
Sculptured Thin Films

Assemblies of Parallel Curved Nanowires/Submicronwires

Controllable Nanowire Shape

2-D - nematic
3-D - helicoidal


Matthew Pickett
1µm
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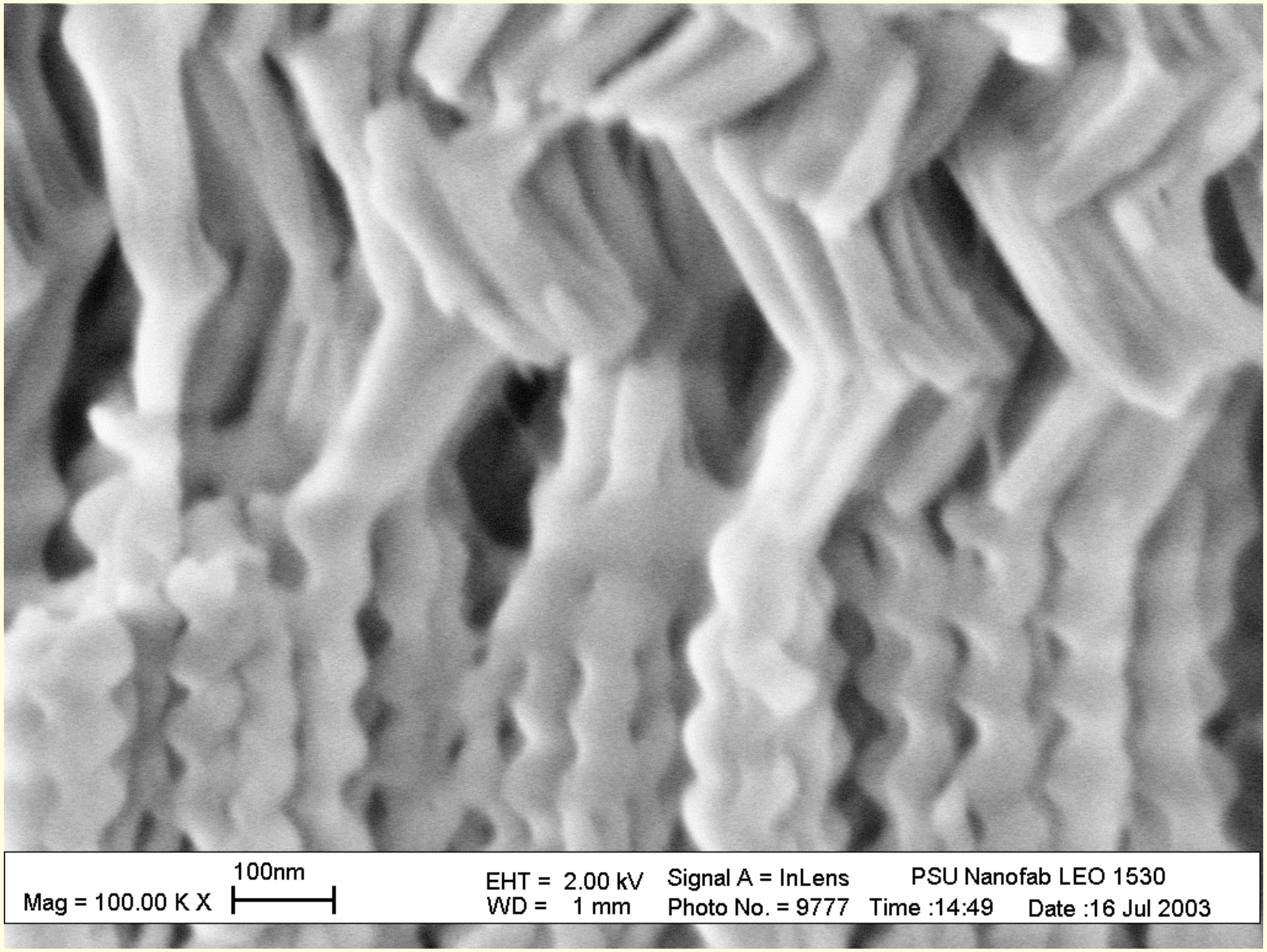
EHT = 3.00 kV
WD = 2 mm
Signal A = InLens
Photo No. = 9684
PSU Nanofab LEO 1530
Time :16:34
Date :1 Jul 2003



100nm
Mag = 100.00 K X
EHT = 2.00 kV
WD = 1 mm
Signal A = InLens
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Time :14:49
PSU Nanofab LEO 1530
Date :16 Jul 2003

Sculptured Thin Films

Assemblies of Parallel Curved Nanowires/Submicronwires

Controllable Nanowire Shape

2-D - nematic
3-D - helicoidal
combination morphologies
vertical sectioning

Sculptured Thin Films

Assemblies of Parallel Curved Nanowires/Submicronwires

Controllable Nanowire Shape

2-D - nematic
3-D - helicoidal
combination morphologies
vertical sectioning

Nanoengineered Materials (1-3 nm clusters)

Controllable Porosity (10-90 %)

Sculptured Thin Films

Antecedents:

(i) Young and Kowal - 1959

(ii) Niuewenhuizen & Haanstra - 1966

(iii) Motohiro & Taga - 1989

Conceived as an optical material by Lakhtakia & Messier (1992-1995)

Sculptured Thin Films

Collaborators:

(i) Weiglhofer, University of Glasgow

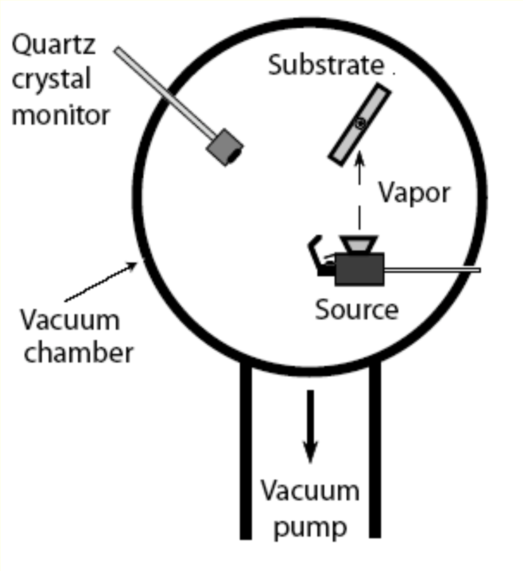
(ii) Robbie & Brett, University of Alberta

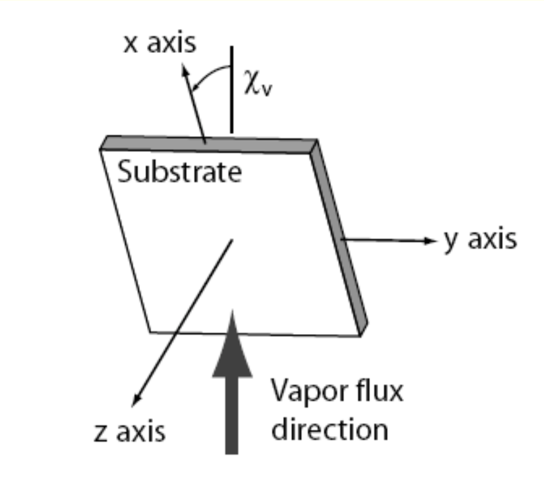
(iii) McCall,Imperial College London

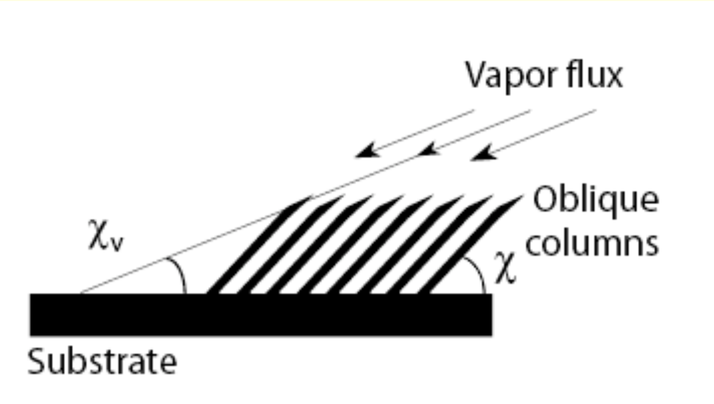
(iv) Hodgkinson, University of Otago

(v) Penn State Colleagues & Students

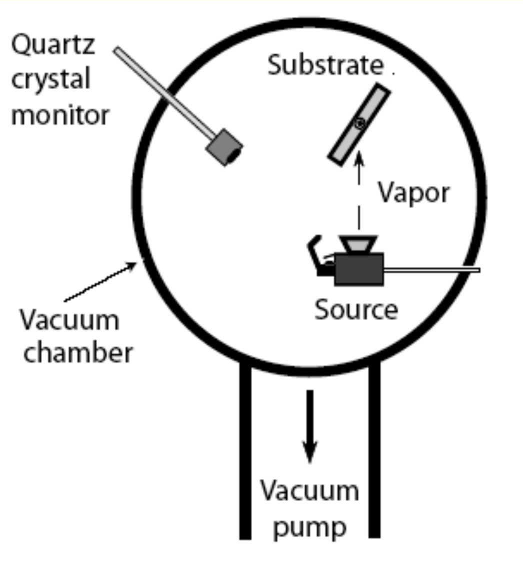
Physical Vapor Deposition
(Columnar Thin Films)

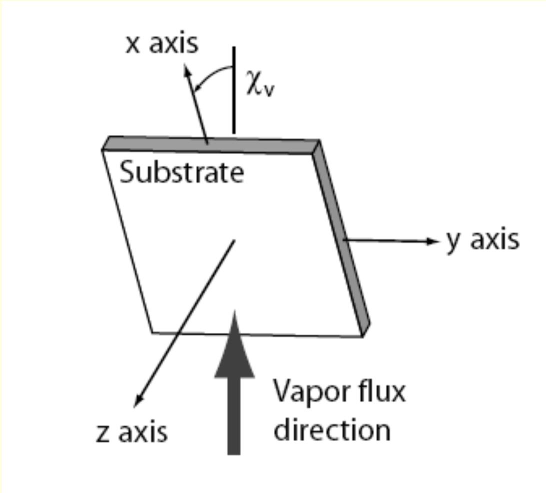






Physical Vapor Deposition
(Sculptured Thin Films)





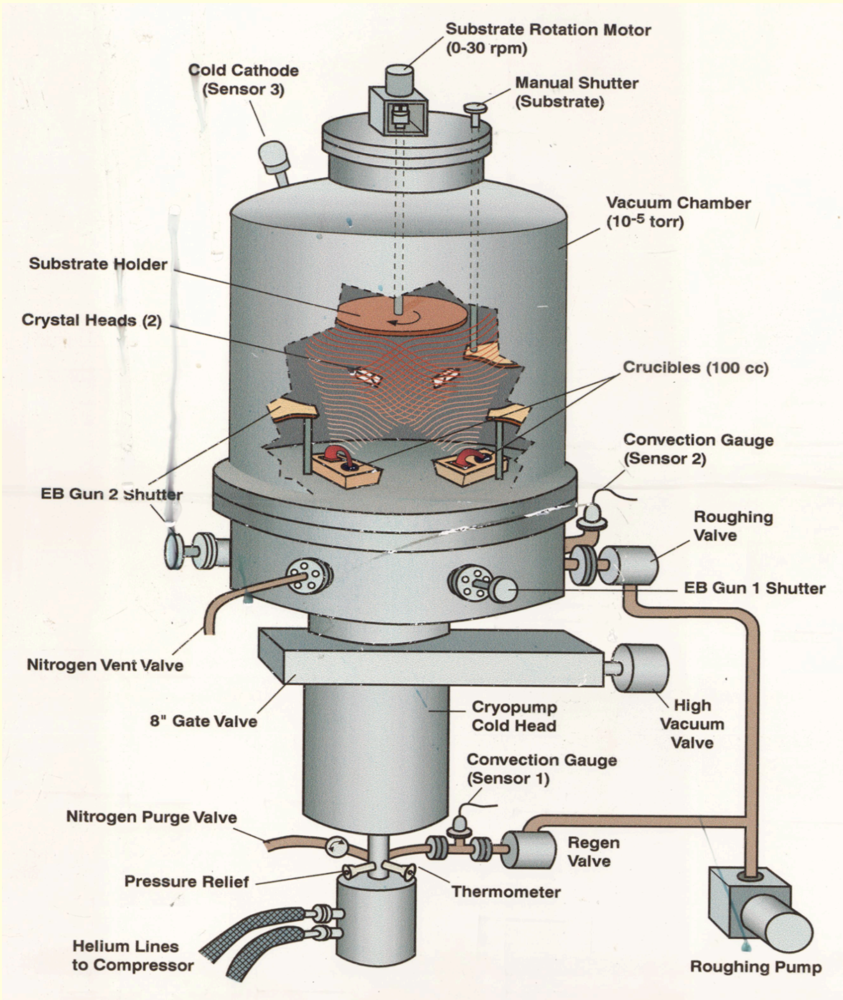
Rotate about y axis for nematic morphology

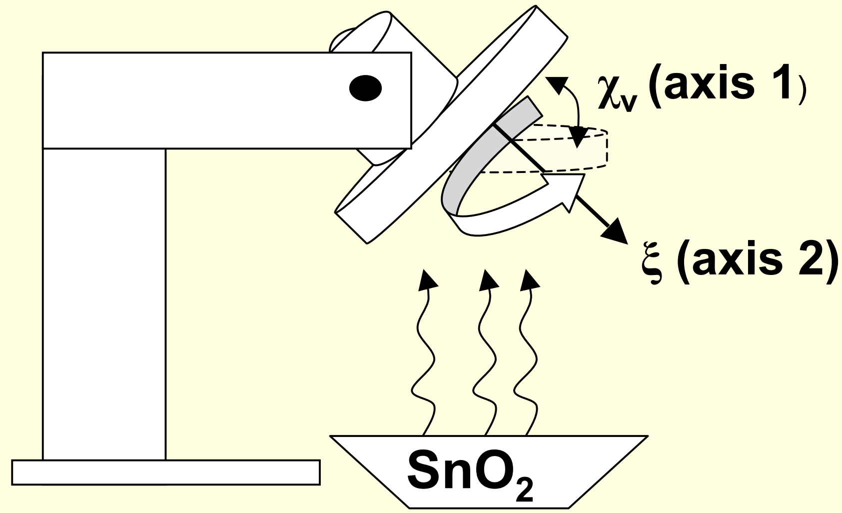
Rotate about z axis for helicoidal morphology

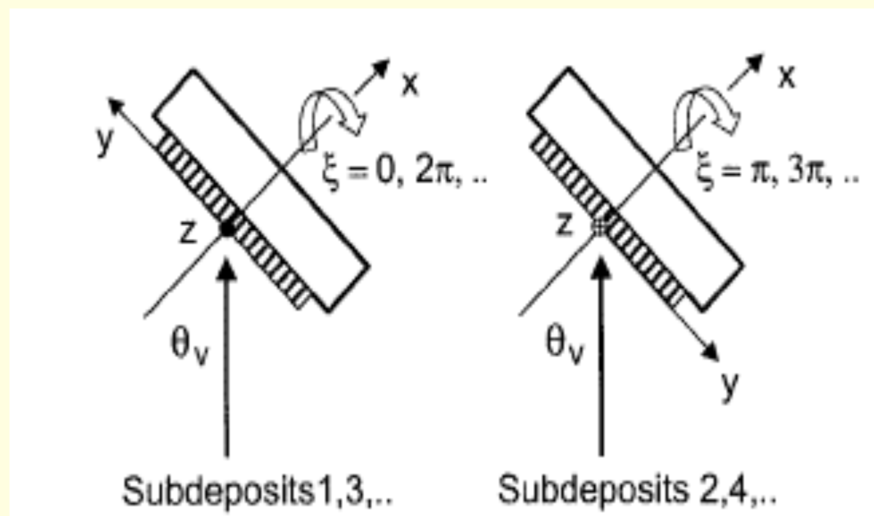
Mix and match rotations for complex morphologies

Physical Vapor Deposition

(Serial Bideposition)







Adapted for STFs by Hodgkinson

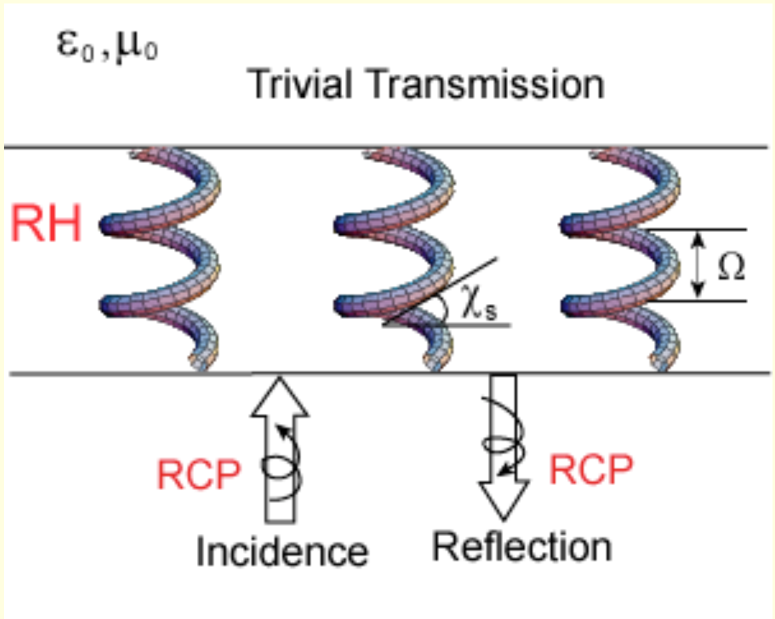
Sculptured Thin Films

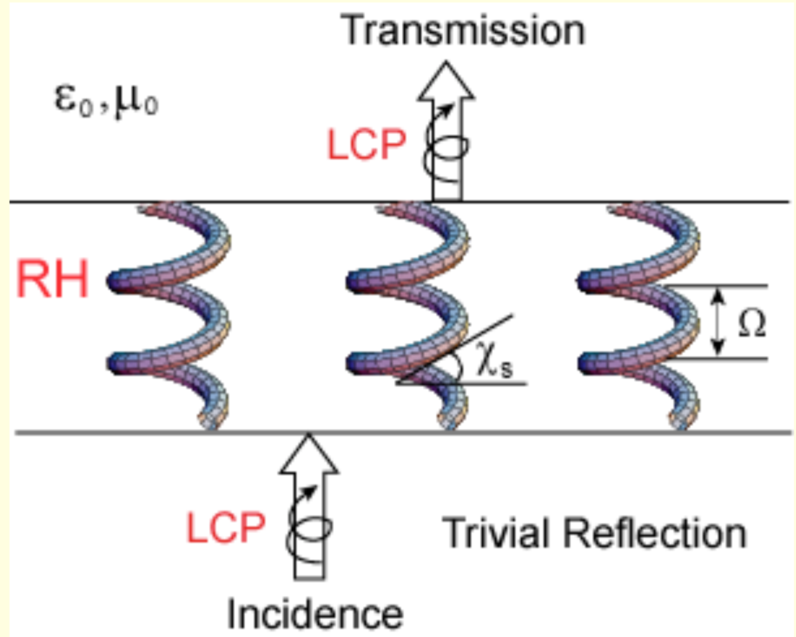
Optical Devices:	Polarization Filters
	Bragg Filters
	Ultranarrowband Filters
	Fluid Concentration Sensors
	Bacterial Sensors
Biomedical Applications:	Tissue Scaffolds
	Drug/Gene Delivery
	Bone Repair
	Virus Traps

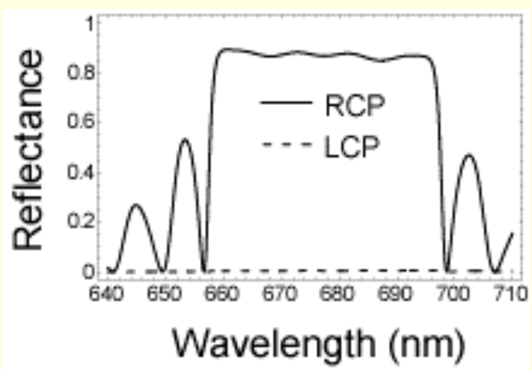
Other Applications

OPTICAL APPLICATIONS

Chiral STFs: Circular Bragg Phenomenon







A simple explanation (Coupled-Wave Theory):

- Co-handed wave: Scalar Bragg grating
- Cross-handed wave: Homogeneous bulk medium

Chiral STF as CP Filter

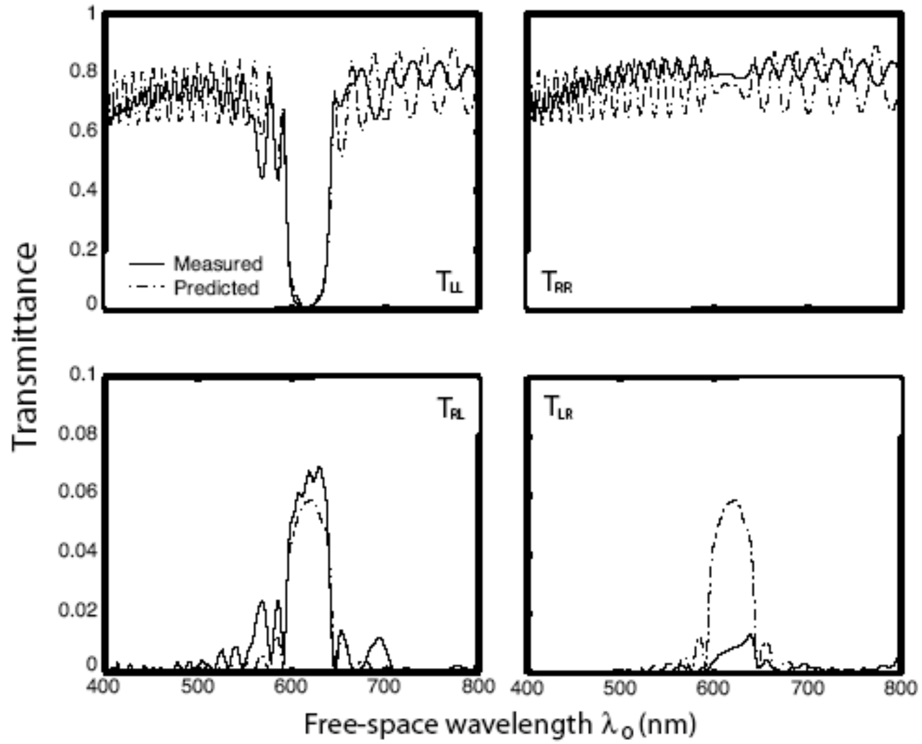


Figure 10.2: Predicted and measured transmittances of a circular polarization filter as functions of the free-space wavelength λ_0 for normal incidence. The filter is a chiral STF of patinal titanium oxide. The reference permittivity dyadic was predicted with $\epsilon_s = 6.3 + i0.012$, $\epsilon_v = 1$, $f_v = 0.421$, $\gamma_\tau^{(s)} = \gamma_\tau^{(v)} = 20$, and $\gamma_b^{(s)} = \gamma_b^{(v)} = 1.06$ set in Program 6.1. The other parameters are $\chi = 47$ deg, $h = -1$, $\Omega = 173$ nm, $L = 30\,\Omega$, and $\psi = 0$ deg. (Adapted from Sherwin et al. [109] with permission of Elsevier.)

Spectral Hole Filter

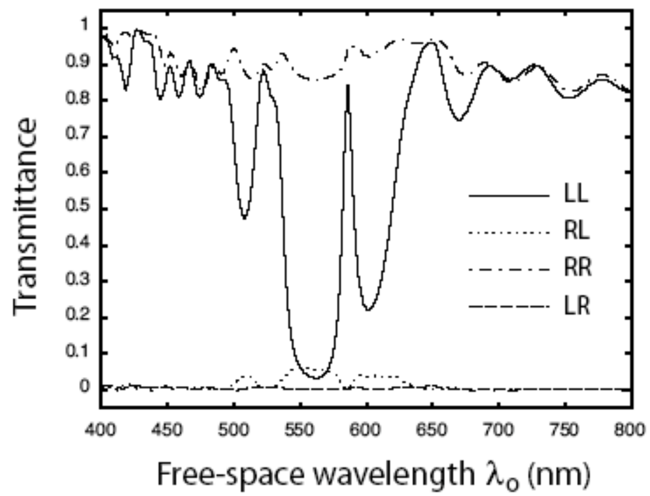


Figure 10.10: Measured transmittances of a narrow bandpass filter comprising an isotropic homogeneous spacer of hafnium oxide interposed between two identical, structurally left-handed, chiral STF sections of titanium oxide. Evidence of a hole in the spectrum of R_{LL} at 580-nm wavelength is provided by the spectrum of T_{LL}. (Adapted from Hodgkinson et al. [125] with permission of Elsevier.)

Fluid Concentration Sensor

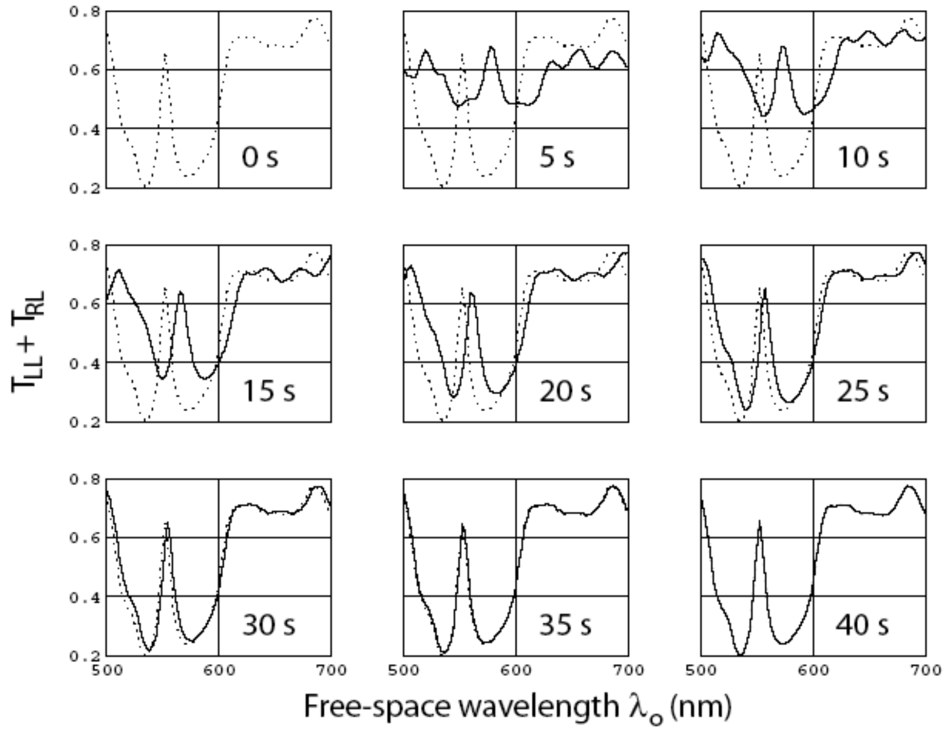


Figure 10.22: Optical response of a narrow bandpass filter, described by Eq. (10.17) and made of two structurally left-handed chiral STF sections, on infiltration by water vapor. The dotted lines indicate the measured transmittance spectrum when the filter was dry. The filter was flooded with water and then allowed to recover by evaporation in air. Transmittance spectrums recorded at 5-s intervals after the flooding are shown. (Adapted from Lakhtakia et al. [105] with permission of Elsevier.)

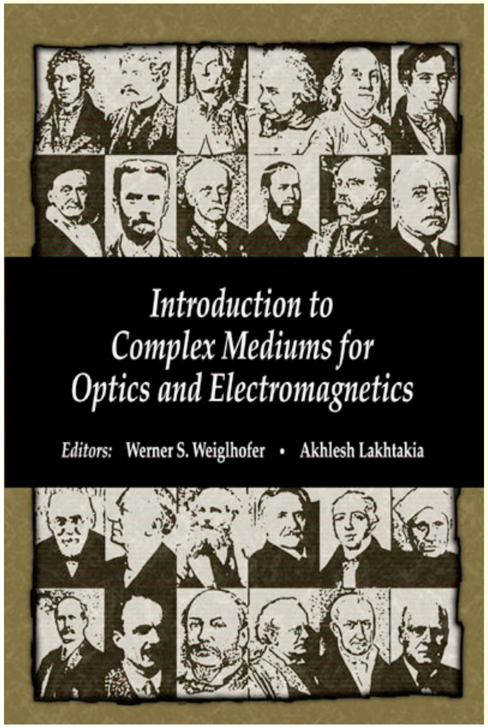
OPTICAL MODELING

Optical Modeling of STFs

$$\mathbf{D}(\mathbf{r},\omega) = \epsilon_0 \, \underline{\underline{S}}(z) \bullet \Big[\underline{\underline{\epsilon}}_{ref}(\omega) \bullet \underline{\underline{S}}^T(z) \bullet \mathbf{E}(\mathbf{r},\omega) + \underline{\underline{\alpha}}_{ref}(\omega) \bullet \underline{\underline{S}}^T(z) \bullet \mathbf{H}(\mathbf{r},\omega) \Big] \,,$$

$$\mathbf{B}(\mathbf{r},\omega) = \mu_0 \, \underline{\underline{S}}(z) \bullet \Big[\underline{\underline{\beta}}_{ref}(\omega) \bullet \underline{\underline{S}}^T(z) \bullet \mathbf{E}(\mathbf{r},\omega) + \underline{\underline{\mu}}_{ref}(\omega) \bullet \underline{\underline{S}}^T(z) \bullet \mathbf{H}(\mathbf{r},\omega) \Big] \,,$$

Linear
Bianisotropic
Materials



SPIE Press (2003)

$$\underline{\underline{S}}_x(z) = \mathbf{u}_x\mathbf{u}_x + (\mathbf{u}_y\mathbf{u}_y + \mathbf{u}_z\mathbf{u}_z)\cos\xi(z) + (\mathbf{u}_z\mathbf{u}_y - \mathbf{u}_y\mathbf{u}_z)\sin\xi(z)\,,$$

$$\underline{\underline{S}}_y(z) = \mathbf{u}_y\mathbf{u}_y + (\mathbf{u}_x\mathbf{u}_x + \mathbf{u}_z\mathbf{u}_z)\cos\tau(z) + (\mathbf{u}_z\mathbf{u}_x - \mathbf{u}_x\mathbf{u}_z)\sin\tau(z)\,,$$

$$\underline{\underline{S}}_z(z) = \mathbf{u}_z\mathbf{u}_z + (\mathbf{u}_x\mathbf{u}_x + \mathbf{u}_y\mathbf{u}_y)\cos\zeta(z) + (\mathbf{u}_y\mathbf{u}_x - \mathbf{u}_x\mathbf{u}_y)\sin\zeta(z)\,.$$

Optical Modeling of STFs

Dielectric Materials

$$\begin{aligned}
\mathbf{D}(\mathbf{r},\omega) &= \epsilon_0 \,\underline{\underline{\epsilon}}_r(z,\omega) \bullet \mathbf{E}(\mathbf{r},\omega) \\
&= \epsilon_0 \,\underline{\underline{S}}(z) \bullet \underline{\underline{\epsilon}}_{ref}(\omega) \bullet \underline{\underline{S}}^T(z) \bullet \mathbf{E}(\mathbf{r},\omega)\,, \\
\mathbf{B}(\mathbf{r},\omega) &= \mu_0 \,\mathbf{H}(\mathbf{r},\omega)\,.
\end{aligned}$$

Optical Modeling of STFs

Locally Orthorhombic Materials

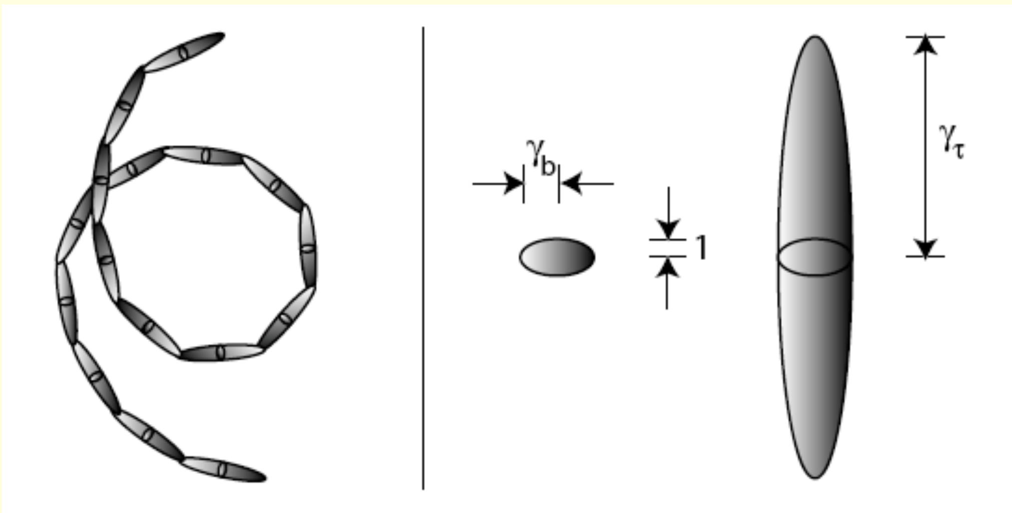
$$\begin{aligned}\mathbf{D}(\mathbf{r},\omega) &= \epsilon_0\, \underline{\underline{\epsilon}}_r(z,\omega) \bullet \mathbf{E}(\mathbf{r},\omega) \\ &= \epsilon_0\, \underline{\underline{S}}(z) \bullet \underline{\underline{\epsilon}}_{ref}(\omega) \bullet \underline{\underline{S}}^T(z) \bullet \mathbf{E}(\mathbf{r},\omega)\,, \\ \mathbf{B}(\mathbf{r},\omega) &= \mu_0\, \mathbf{H}(\mathbf{r},\omega)\,.\end{aligned}$$

$$\underline{\underline{\epsilon}}_{ref}(\omega) = \underline{\underline{\hat{S}}}_y(\chi) \bullet \underline{\underline{\epsilon}}^o_{ref}(\omega) \bullet \underline{\underline{\hat{S}}}^T_y(\chi)$$

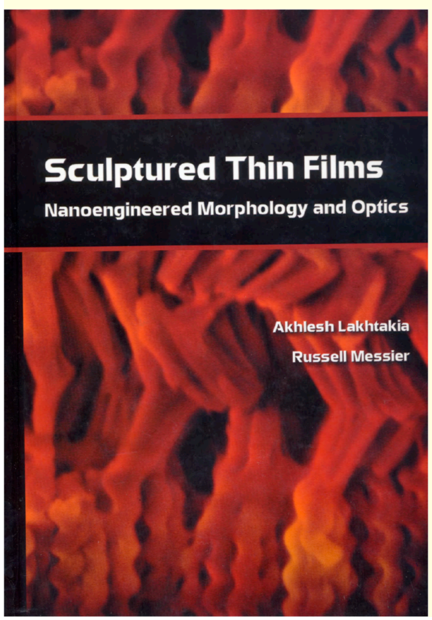
$$\underline{\underline{\epsilon}}^o_{ref}(\omega) = \underline{\underline{\epsilon}}_{ref}(\omega)\Big|_{\chi=0} = \epsilon_a(\omega)\,\mathbf{u}_z\mathbf{u}_z + \epsilon_b(\omega)\,\mathbf{u}_x\mathbf{u}_x + \epsilon_c(\omega)\,\mathbf{u}_y\mathbf{u}_y$$

$$\underline{\underline{\hat{S}}}_y(\chi) = \mathbf{u}_y\mathbf{u}_y + (\mathbf{u}_x\mathbf{u}_x + \mathbf{u}_z\mathbf{u}_z)\,\cos\chi + (\mathbf{u}_z\mathbf{u}_x - \mathbf{u}_x\mathbf{u}_z)\,\sin\chi$$

Optical Modeling of STFs



Homogenize a collection of parallel ellipsoids to get $\underline{\underline{\epsilon}}^{o}_{ref}(\omega)$



Mathematica Program

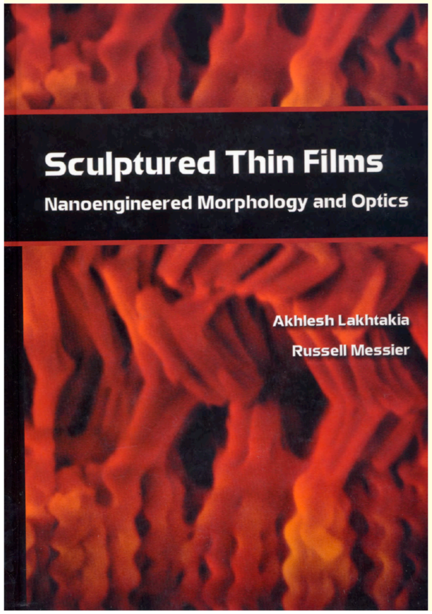
Sherwin and Lakhtakia (2001-2003):
Bruggeman formalism

Optical Modeling of STFs

Wave Propagation

$$\mathbf{E}(\mathbf{r},\omega) = \mathbf{e}(z,\kappa,\psi,\omega)\ \exp\left[i\kappa(x\cos\psi + y\sin\psi)\right]$$
$$\mathbf{H}(\mathbf{r},\omega) = \mathbf{h}(z,\kappa,\psi,\omega)\ \exp\left[i\kappa(x\cos\psi + y\sin\psi)\right]$$

$$\nabla \times \mathbf{E}(\mathbf{r},\omega) = i\omega\mathbf{B}(\mathbf{r},\omega)\,,$$
$$\nabla \times \mathbf{H}(\mathbf{r},\omega) = -i\omega\mathbf{D}(\mathbf{r},\omega)\,,$$



Mathematica Program

$$\frac{d}{dz}\left[\mathbf{f}(z,\kappa,\psi,\omega)\right] = i\left[\mathbf{P}(z,\kappa,\psi,\omega)\right]\left[\mathbf{f}(z,\kappa,\psi,\omega)\right].$$

$$\left[\mathbf{f}(z,\kappa,\psi,\omega)\right] = \begin{bmatrix} e_x(z,\kappa,\psi,\omega) \\ e_y(z,\kappa,\psi,\omega) \\ h_x(z,\kappa,\psi,\omega) \\ h_y(z,\kappa,\psi,\omega) \end{bmatrix}$$

EMERGING DIRECTIONS

1. LIGHT EMITTERS

LIGHT EMITTERS

- Luminophores inserted in a chiral STF
- Co- and contra-wound photonic source filaments
- Calculations using Maxwell postulates
  - volume fraction of filaments
  - wavelength
  - co/contra-wound

LIGHT EMITTERS

Co-wound

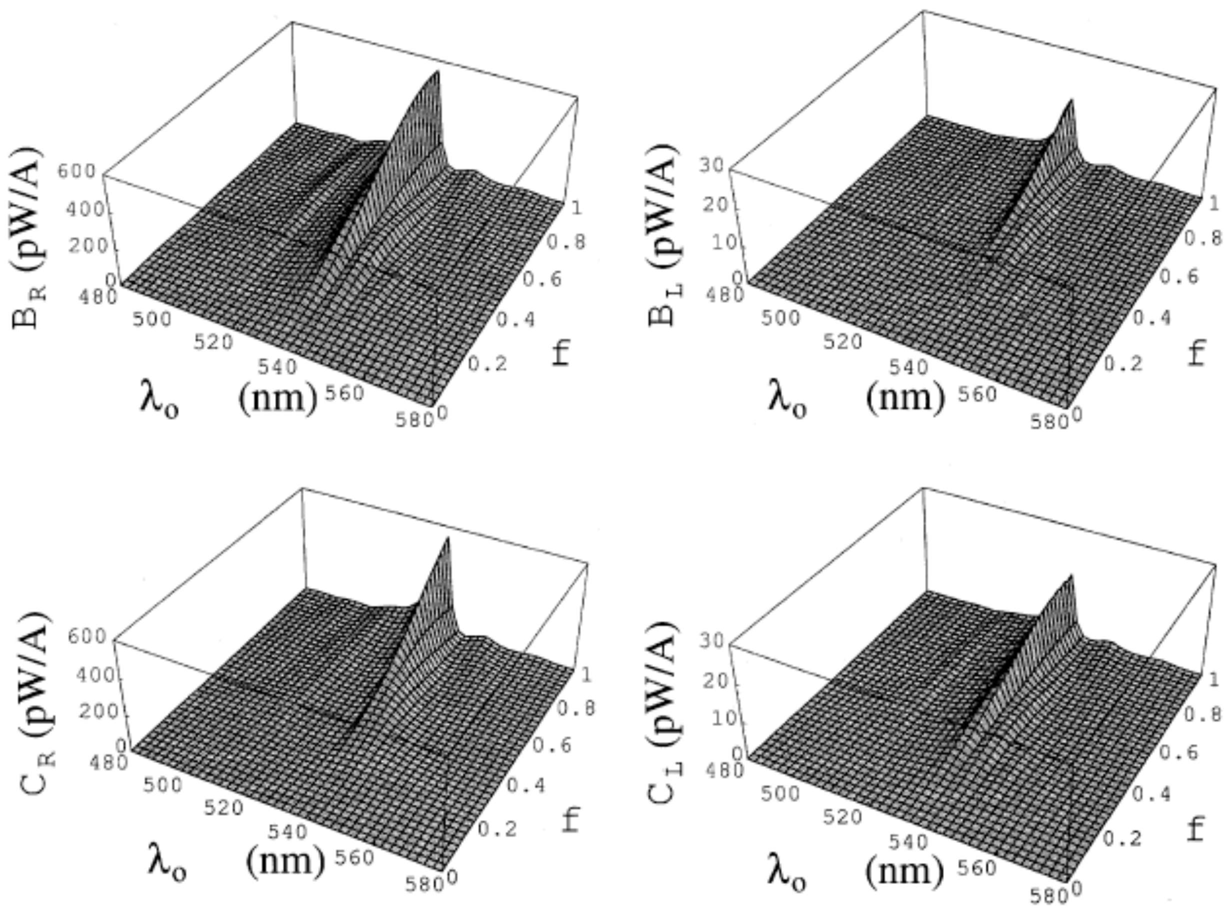


Fig. 1. Computed spectrums of the emission efficiencies $\mathscr{B}_{R,L}$ and $\mathscr{C}_{R,L}$ as functions of the fraction f of a chiral STF occupied by co-wound photon source filaments and the free-space wavelength λ_0. See the text for the constitutive and other parameters used. The Bragg regime for the selected parameters is $\lambda_0 \in [513.4, 531.8]$ nm.

LIGHT EMITTERS

Contra-wound

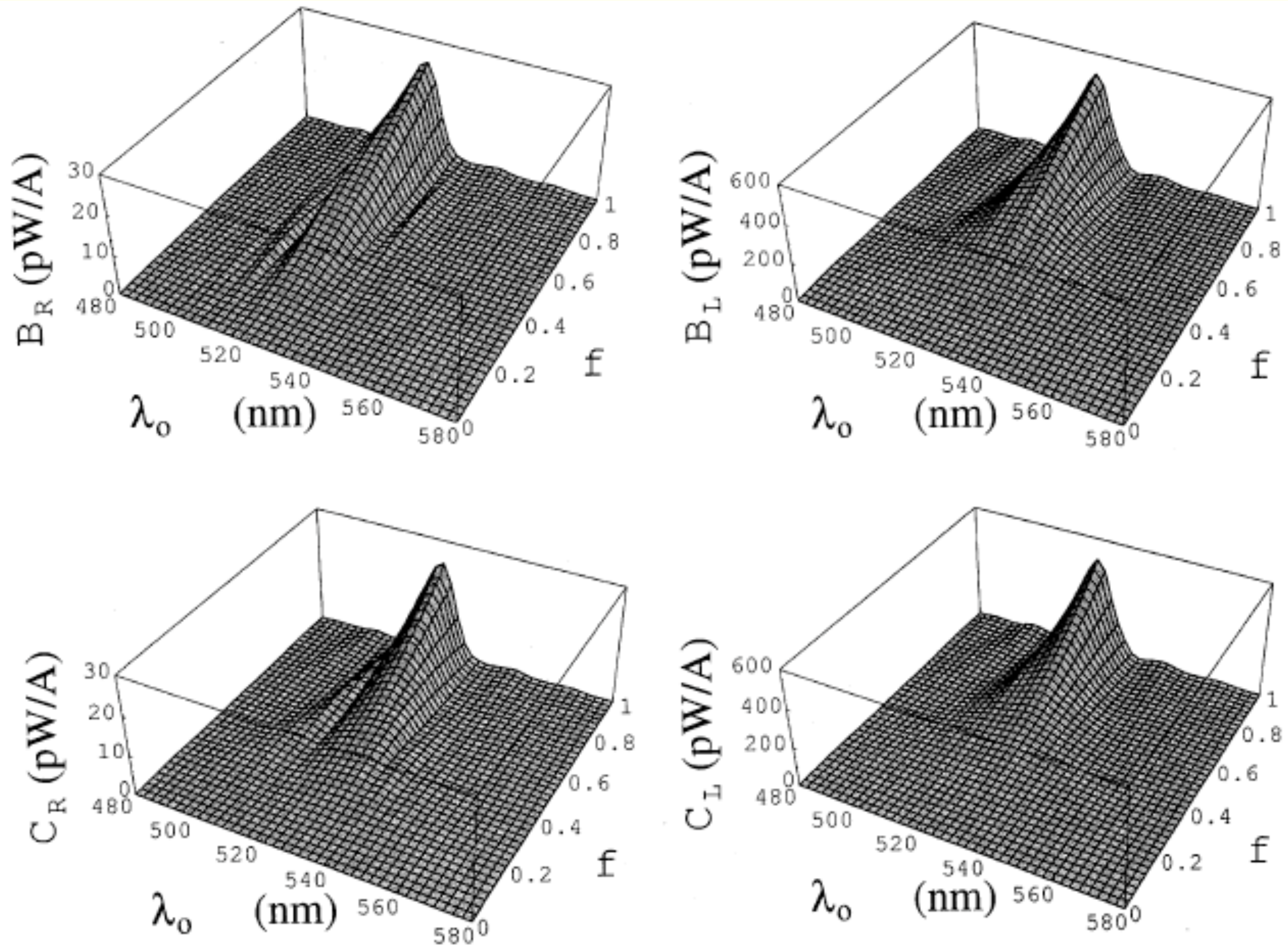


Fig. 2. Same as Fig. 1, except that the photon source filaments are contra-wound.

LIGHT EMITTERS

- Co/contra-wound:

  Clear differences in
  (i) polarization state
  (ii) emission bandwidth

- Dependence on tilt angle χ

1. Lakhtakia, *Opt. Commun.* **188**, 313 (2001)
2. Lakhtakia, *Opt. Commun.* **202**, 103 (2002)
3. Lakhtakia, *MOTL* **37**, 37 (2003)
4. Steltz & Lakhtakia, *Opt. Commun.* **216**, 139 (2003)
   - nonlinear

LIGHT EMITTERS

- Luminophores (Alq3) inserted in a cavity between two chiral STFs

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Optics Communications xxx (2006) xxx–xxx

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Circularly polarized fluorescence from light-emitting microcavities with sculptured-thin-film chiral reflectors

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LIGHT EMITTERS

- Luminophores (Alq3) inserted in a cavity between two chiral STFs

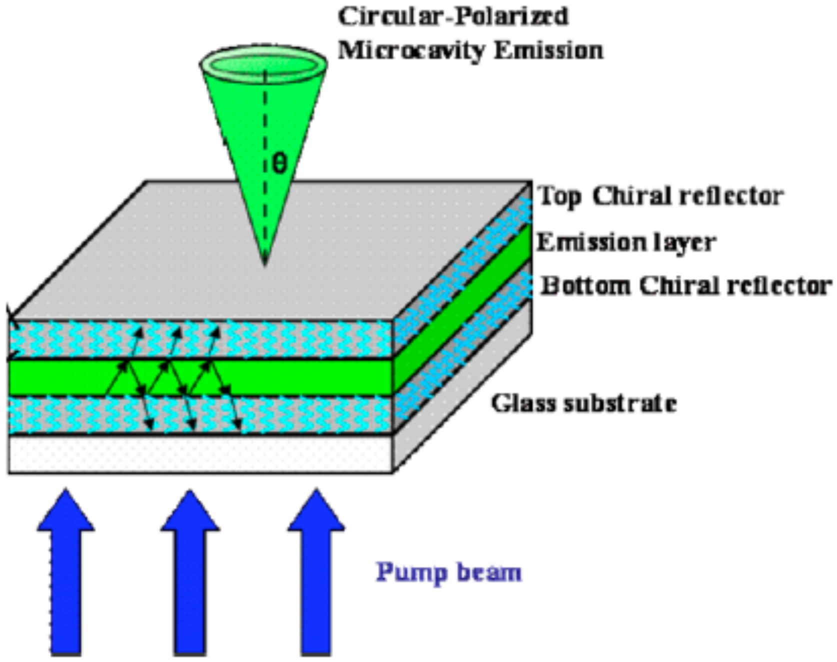


Fig. 3. Schematic of the light-emitting microcavity device incorporating two identical STF chiral reflectors sandwiching a layer of ALq3 molecules. Here, θ denotes the emission cone. The oblique arrows drawn inside the layers simply underscore the back and force bouncing of photons.

LIGHT EMITTERS

- Luminophores (Alq_3) inserted in a cavity between two chiral STFs

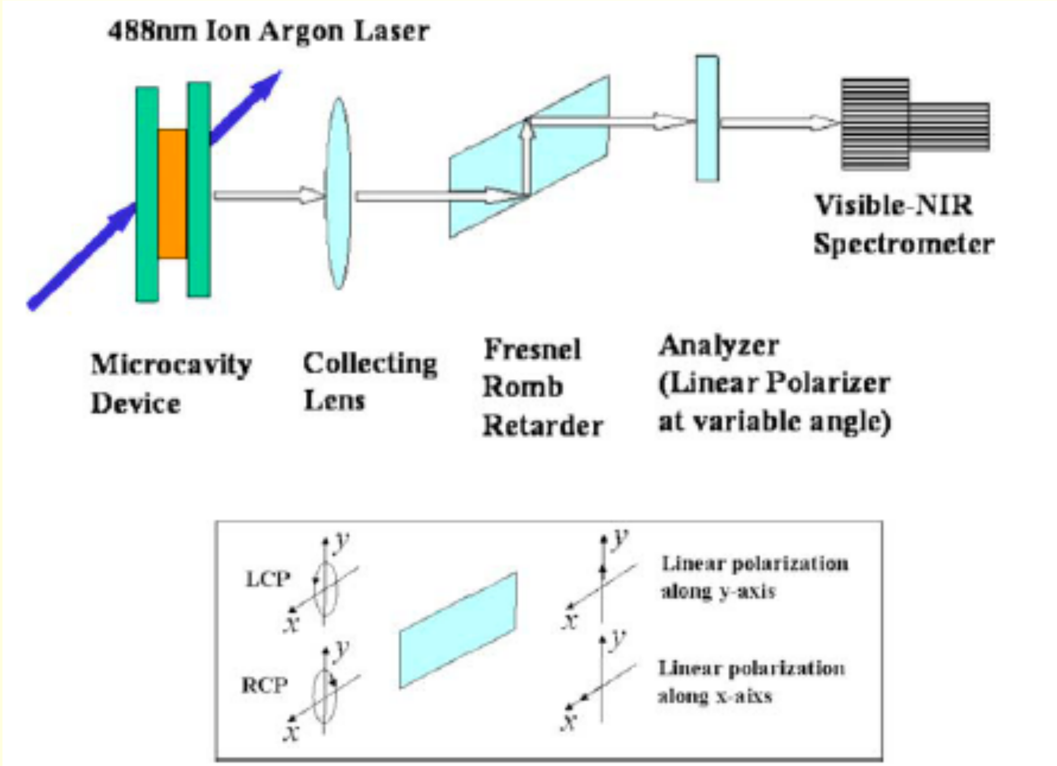
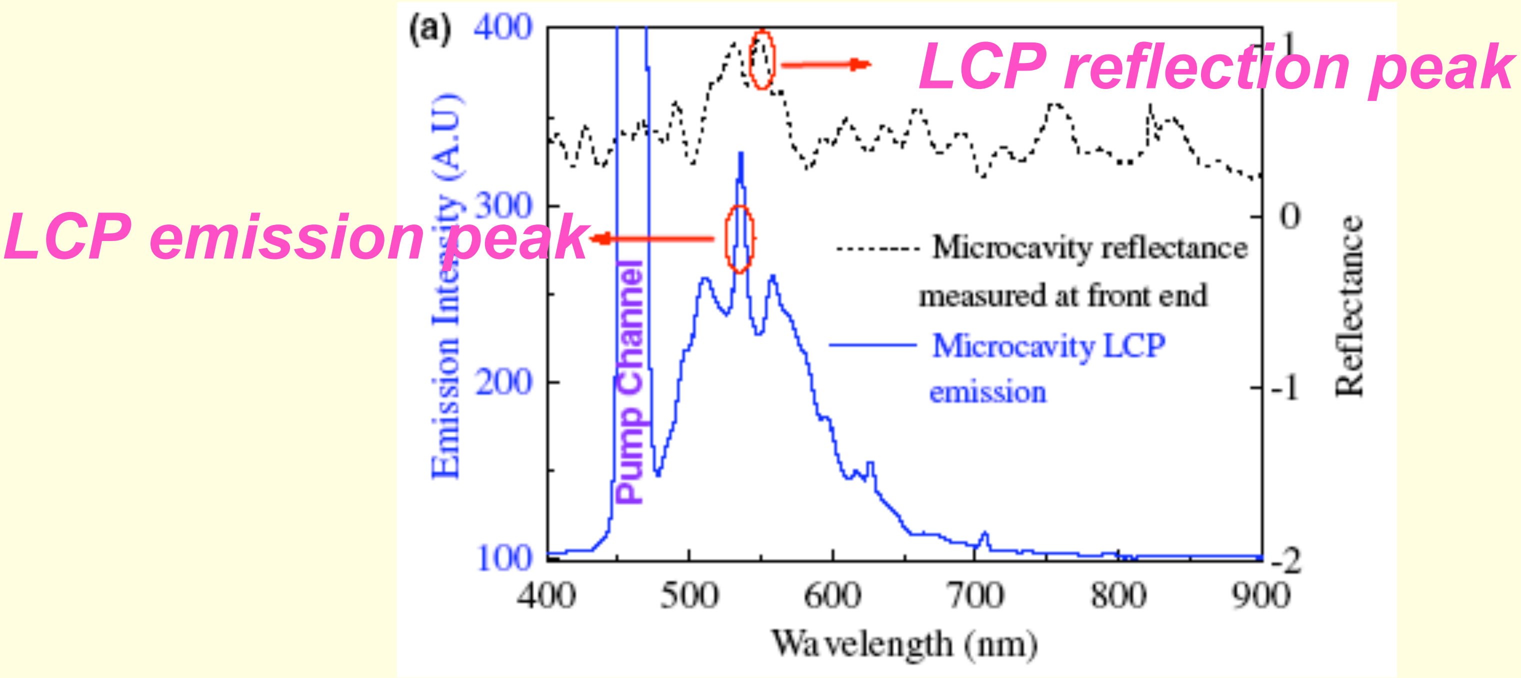


Fig. 4. Schematic of the optical bench used to characterize the circular polarization light-emitting device. The inset shows how a quarter-wave Fresnel-rhomb retarder converts LCP and RCP light beams to the linearly polarized light beams whose polarization directions are orthonormal.

LIGHT EMITTERS

- Luminophores (Alq3) inserted in a cavity between two left-handed chiral STFs



2. STFs WITH GAIN

STFs WITH GAIN

- Chiral STF

$$\underline{\underline{\epsilon}}^{o}_{ref}(\omega) = \underline{\underline{\epsilon}}_{ref}(\omega)\Big|_{\chi=0} = \epsilon_a(\omega)\,\mathbf{u}_z\mathbf{u}_z + \epsilon_b(\omega)\,\mathbf{u}_x\mathbf{u}_x + \epsilon_c(\omega)\,\mathbf{u}_y\mathbf{u}_y$$

$$\epsilon_a = 2.5\,(1 + i\delta_\epsilon),\ \epsilon_b = 3.2\,(1 + i\delta_\epsilon),\ \epsilon_c = 2.6\,(1 + i\delta_\epsilon)$$

$\delta_\epsilon > 0$ absorption

$\delta_\epsilon < 0$ gain

$\delta_\epsilon = 0$ no absorption, no gain

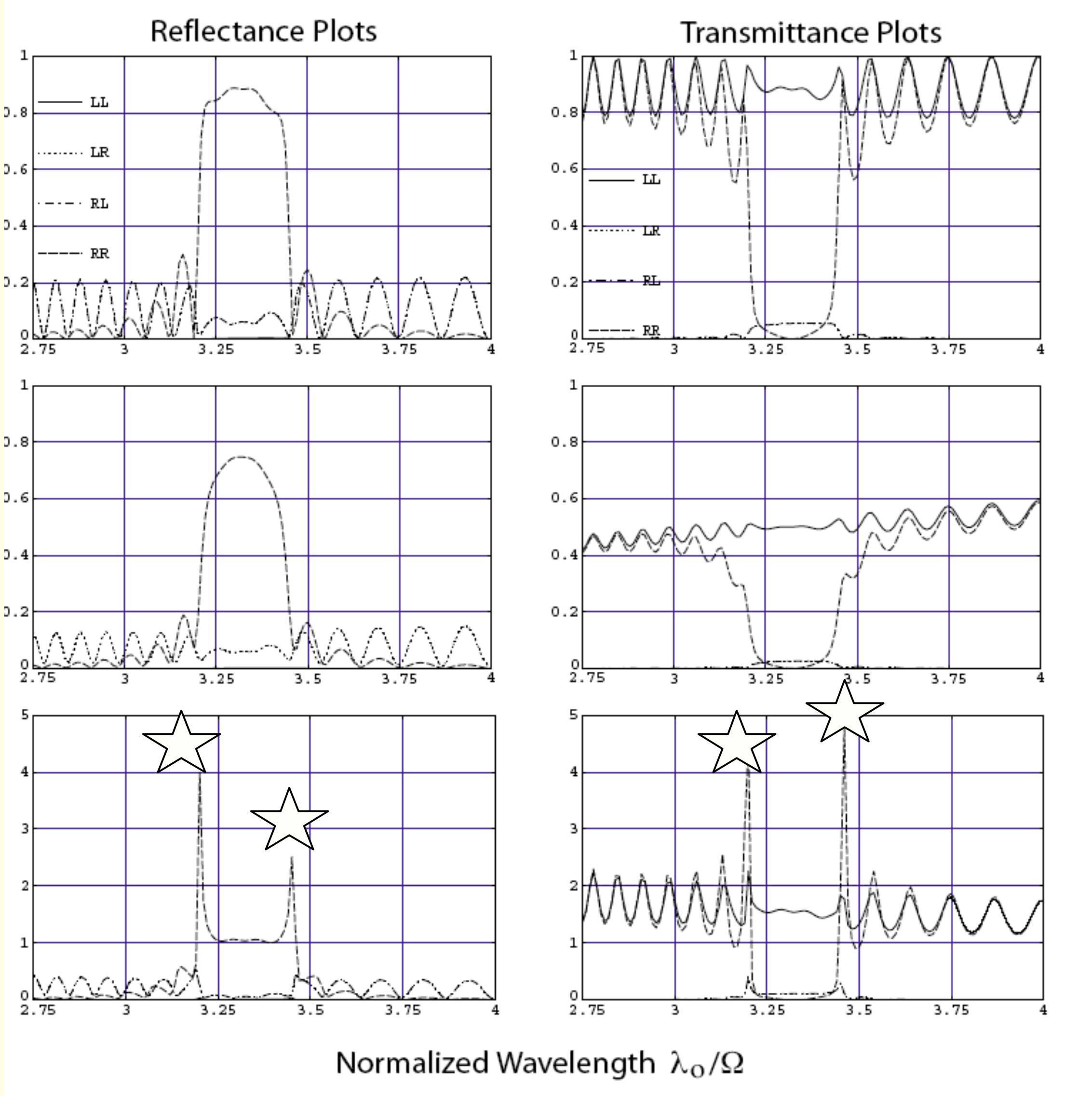
- Solve Maxwell postulates for reflection and transmission

STFs WITH GAIN

No loss, no gain

Loss

Gain



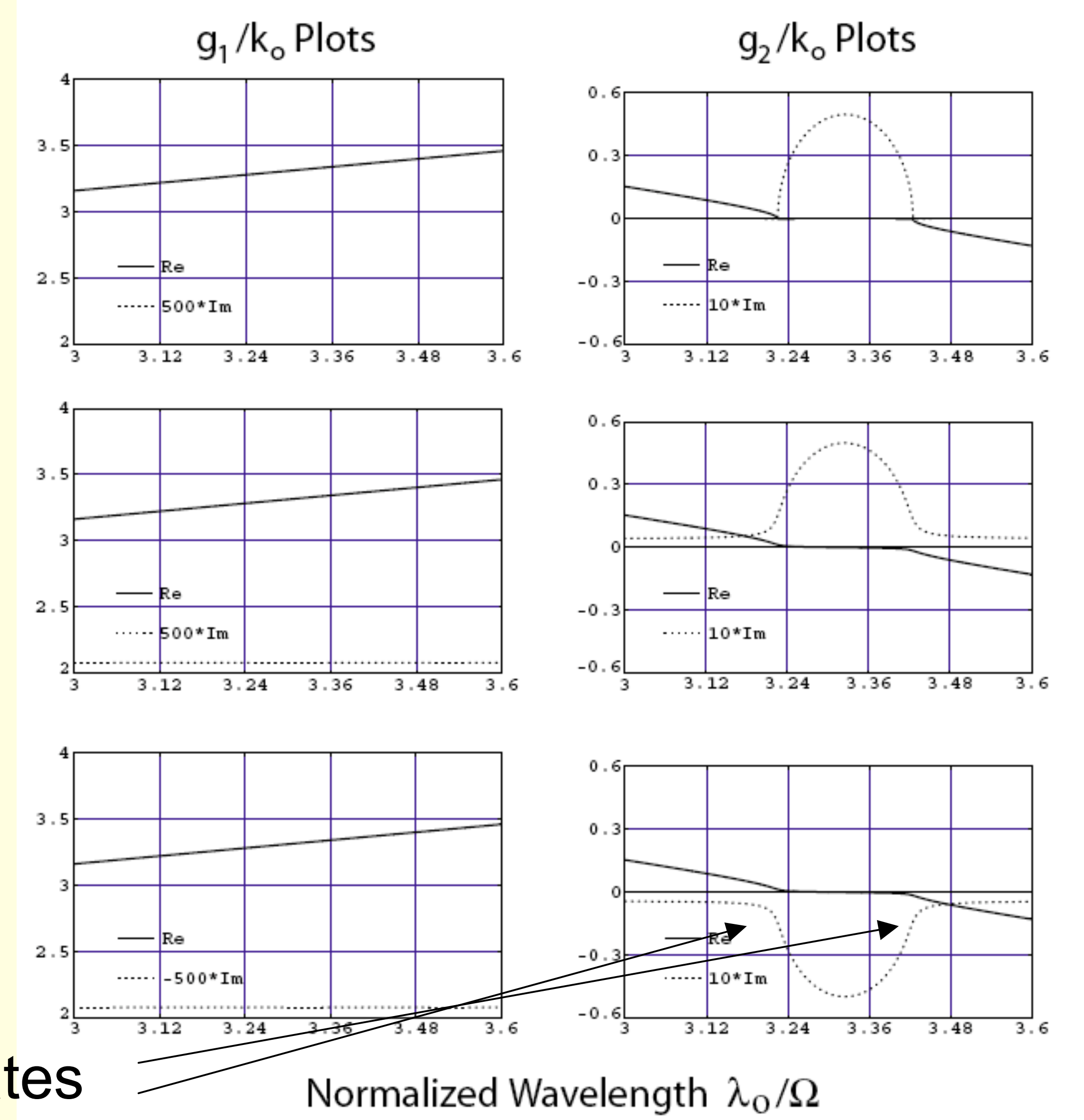
Lakhtakia & Xu, at press

STFs WITH GAIN

No loss, no gain

Loss

Gain



High density of states

STFs WITH GAIN

High Density of States

implies

High Emission

Analogy: Lasing by dye-doped CLCs

3. ELECTRICALLY CONTROLLED STFs

ELECTRICALLY CONTROLLED STFs

$$\underline{\underline{\epsilon}}_{PE}^{-1} = \begin{pmatrix} 1/\epsilon_1^{(0)} + \sum_{K=1}^{3} r_{1K} E_K^{dc} & \sum_{K=1}^{3} r_{6K} E_K^{dc} & \sum_{K=1}^{3} r_{5K} E_K^{dc} \\ \sum_{K=1}^{3} r_{6K} E_K^{dc} & 1/\epsilon_2^{(0)} + \sum_{K=1}^{3} r_{2K} E_K^{dc} & \sum_{K=1}^{3} r_{4K} E_K^{dc} \\ \sum_{K=1}^{3} r_{5K} E_K^{dc} & \sum_{K=1}^{3} r_{4K} E_K^{dc} & 1/\epsilon_3^{(0)} + \sum_{K=1}^{3} r_{3K} E_K^{dc} \end{pmatrix}$$

$$\underline{\underline{\epsilon}}_{ref}^{o} = \underline{\underline{\epsilon}}_{PE}$$

DC voltage across the thickness

ELECTRICALLY CONTROLLED STFs

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Electrically controlled optical bandgap in a structurally chiral material

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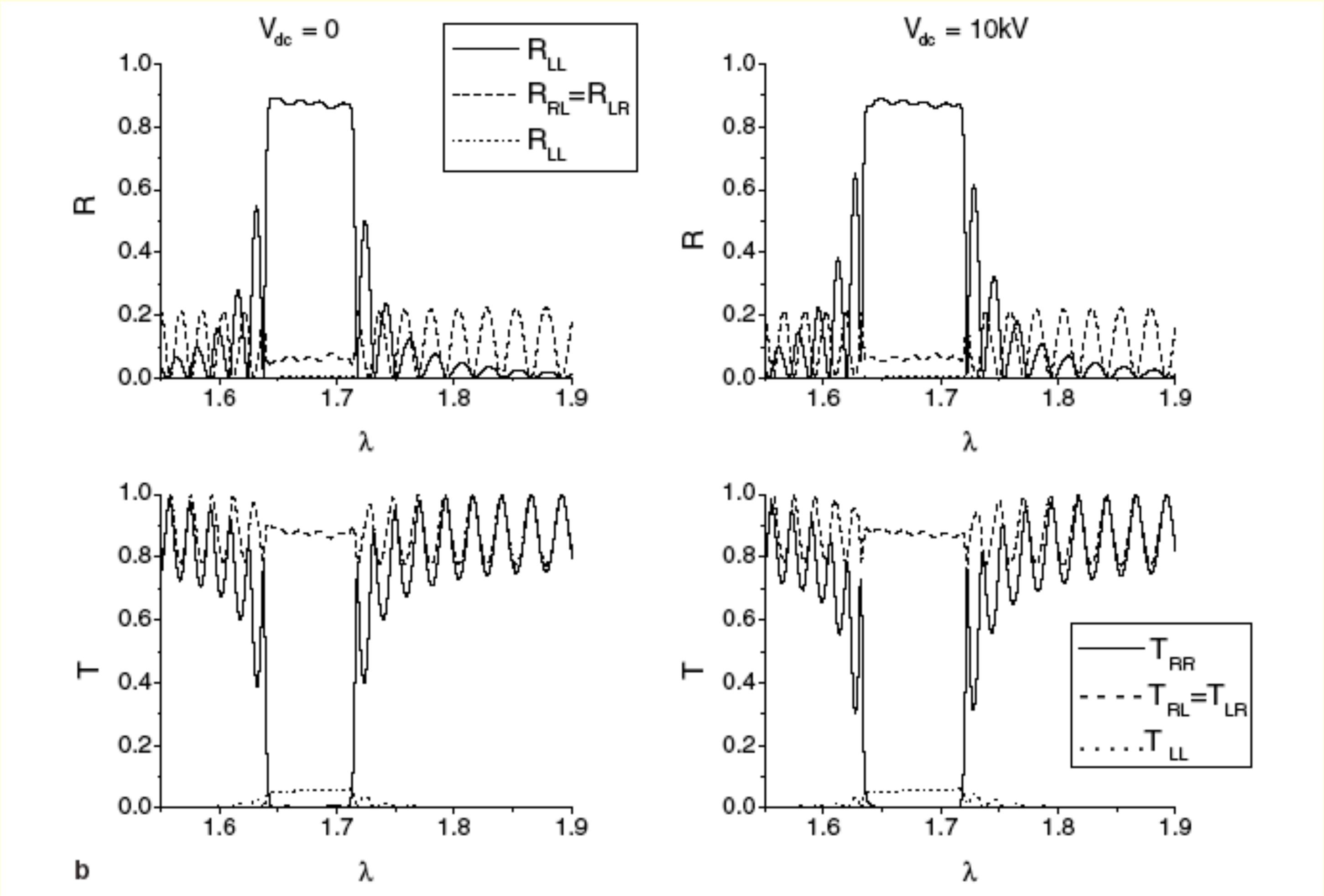
[c] *Photonics Section, Department of Physics, Imperial College, London SW7 2AZ, United Kingdom*

Also:

(1) Reyes & Lakhtakia, *Opt. Commun.,* at press
(2) Lakhtakia & Reyes, *Phys. Rev. E*, submitted

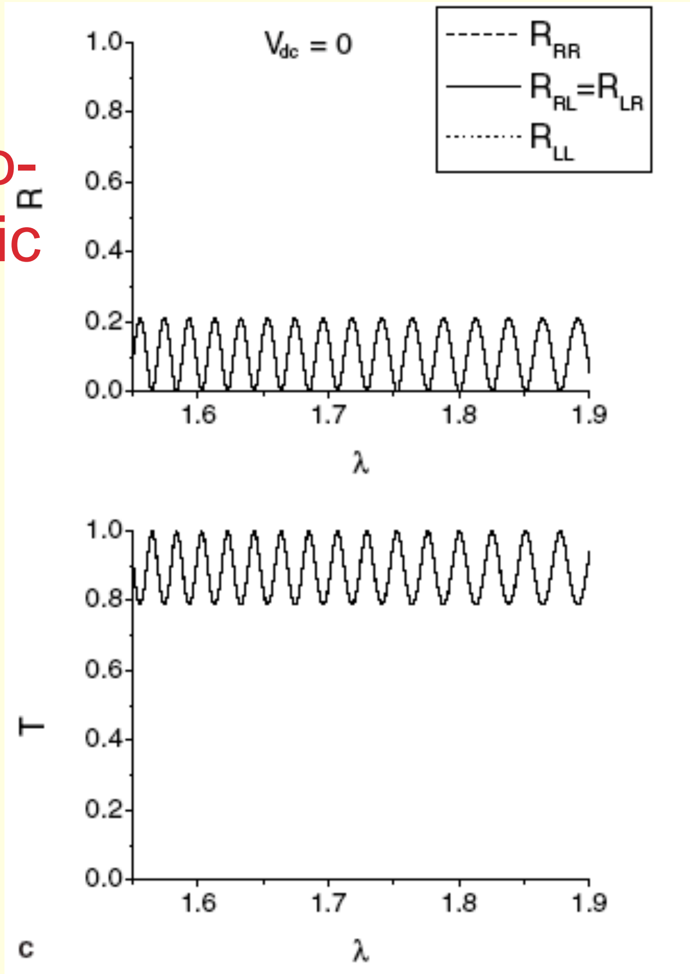
ELECTRICALLY CONTROLLED STFs



Without dc voltage With dc voltage

ELECTRICALLY CONTROLLED STFs

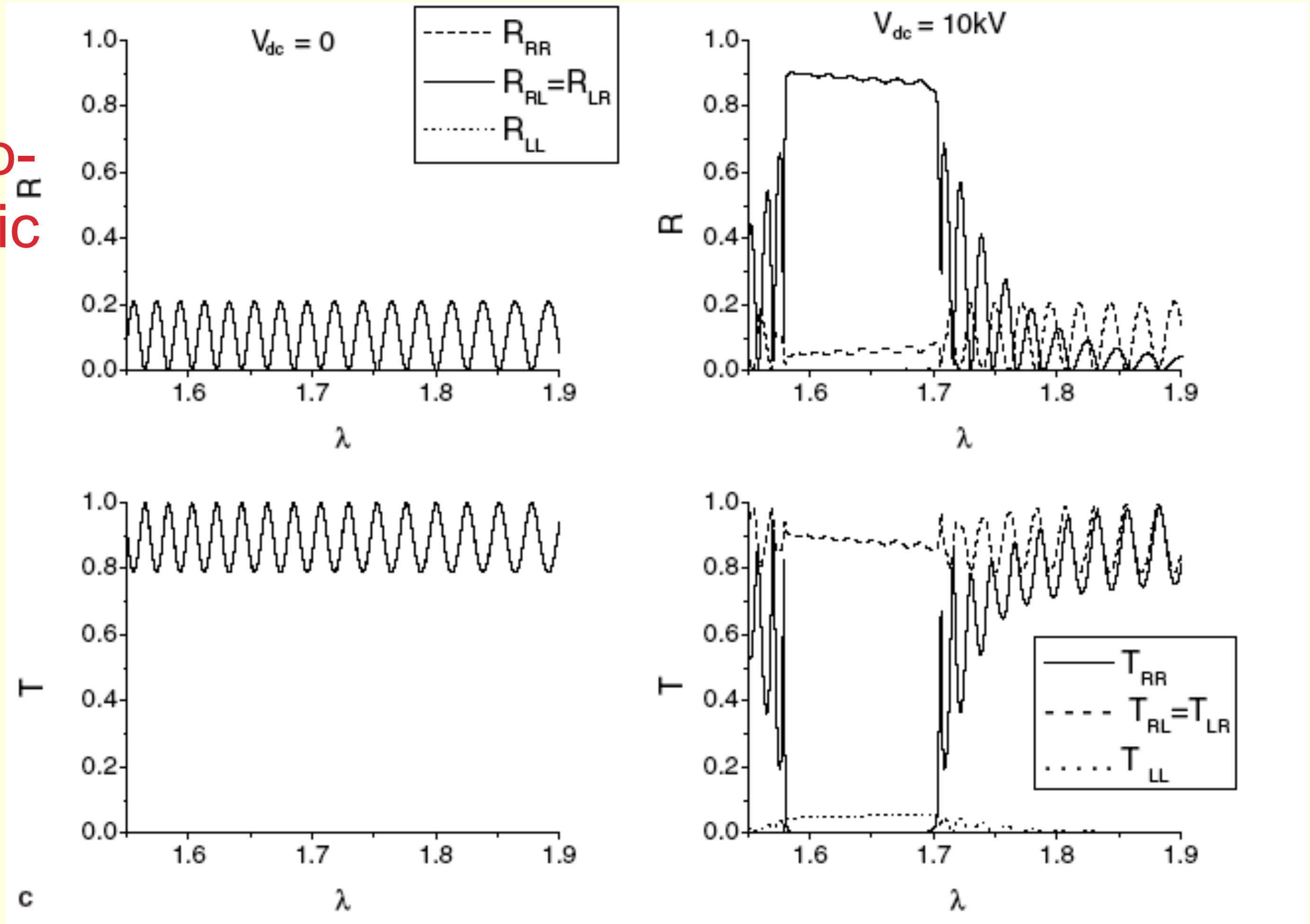
Pseudo-Isotropic point



Without dc voltage

ELECTRICALLY CONTROLLED STFs

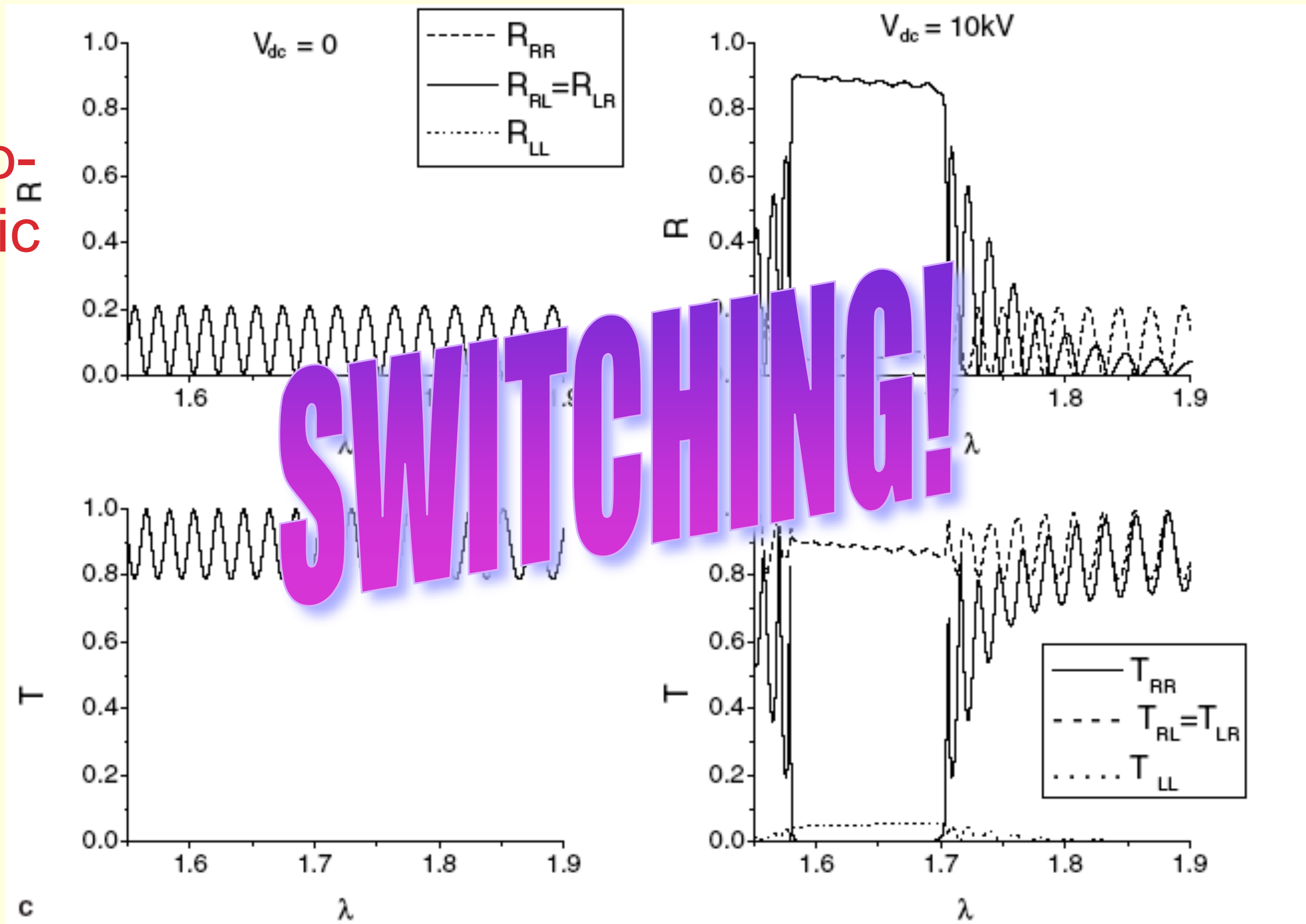
Pseudo-Isotropic point



Without dc voltage With dc voltage

ELECTRICALLY CONTROLLED STFs

Pseudo-Isotropic point



Without dc voltage With dc voltage

4. POLYMERIC STFs

POLYMERIC STFs

1. Replamineform (Multi-Step) Technique
2. Combined CVD-PVD Technique
3. Holographic Lithography

POLYMERIC STFs:
REPLAMINEFORM TECHNIQUE

Suggestion published in 1996

Innovations in Materials Research, Vol. 1, No. 2 (1996) 165-176

**SCULPTURED THIN FILMS (STFS)
FOR OPTICAL, CHEMICAL AND BIOLOGICAL APPLICATIONS**

A. Lakhtakia,[1] R. Messier,[1,2] M. J. Brett[3] and K. Robbie[3]

POLYMERIC STFs:
REPLAMINEFORM TECHNIQUE (3-step)

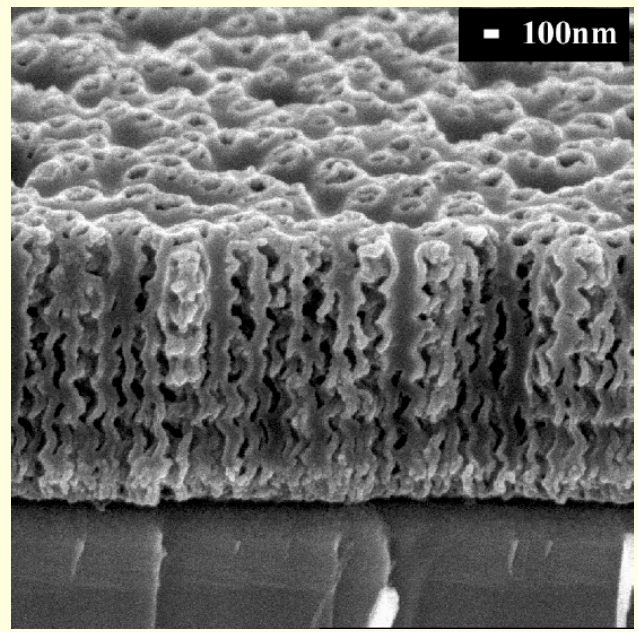
Implementation published in 2001:

Harris, Westra, Brett, *Electrochem. Sol.-St. Lett.* **4**, C39 (2001)

Three-step procedure:

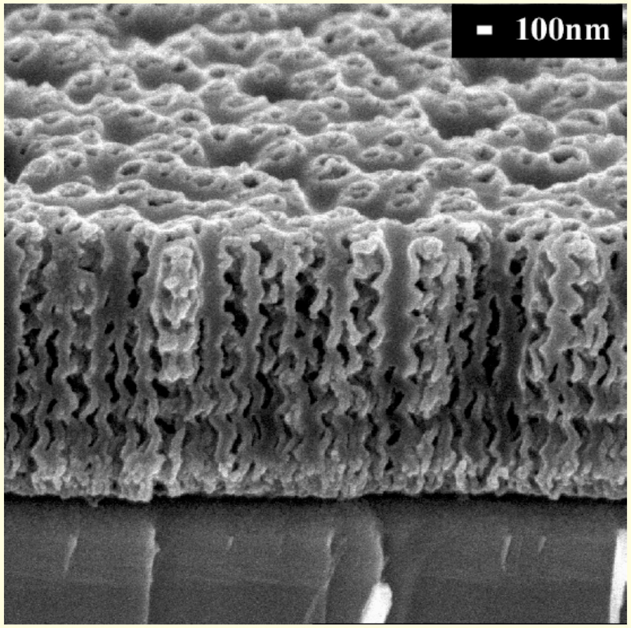
1. Make a chiral STF
2. Fill the void regions with a polymer
3. Etch out the skeleton material

Helical holes



Elias, Harris, Brett, *J.M.S.* **13**, 808 (2004)

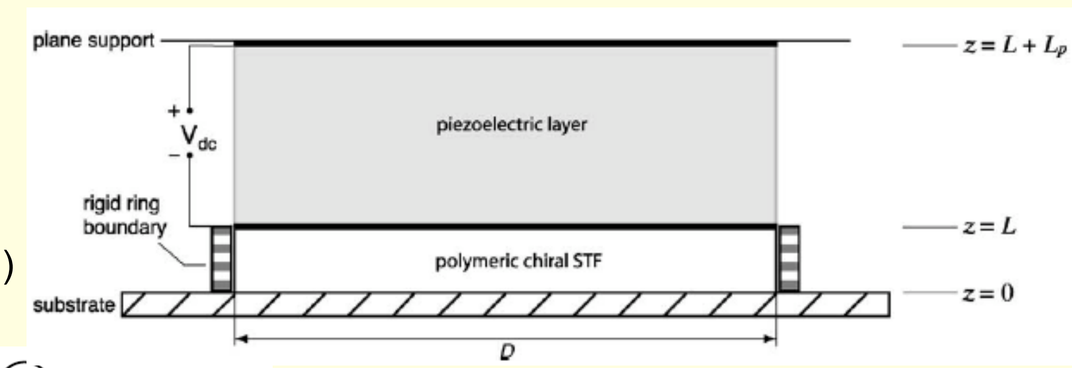
POLYMERIC STFs:
REPLAMINEFORM TECHNIQUE (3-step)



Elias, Harris, Brett, *J.M.S.* **13**, 808 (2004)

Helical holes

Excellent for piezoelectrically controlled STFs



JOURNAL OF MODERN OPTICS, 2003, VOL. 50, NO. 2, 239–249

Taylor & Francis
Taylor & Francis Group

On piezoelectric control of the optical response of sculptured thin films

FEI WANG, AKHLESH LAKHTAKIA[1] and RUSSELL MESSIER

POLYMERIC STFs:
REPLAMINEFORM TECHNIQUE (5-step)

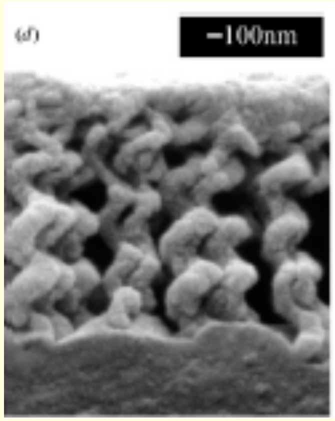
INSTITUTE OF PHYSICS PUBLISHING — JOURNAL OF MICROMECHANICS AND MICROENGINEERING
J. Micromech. Microeng. 15 (2005) 49–54 — doi:10.1088/0960-1317/15/1/008

Large-area microfabrication of three-dimensional, helical polymer structures

A L Elias[1], K D Harris[2], C W M Bastiaansen[2], D J Broer[2,3] and M J Brett[1]

5-step procedure:

1. Make a chiral STF
2. Fill the void regions with polymer A
3. Etch out the skeleton material
4. Fill the void region regions with polymer B
5. Etch out polymer A



POLYMERIC STFs:
COMBINED CVD+PVD TECHNIQUE

1-Step Process

Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Polymer 46 (2005) 9544–9548
polymer
www.elsevier.com/locate/polymer

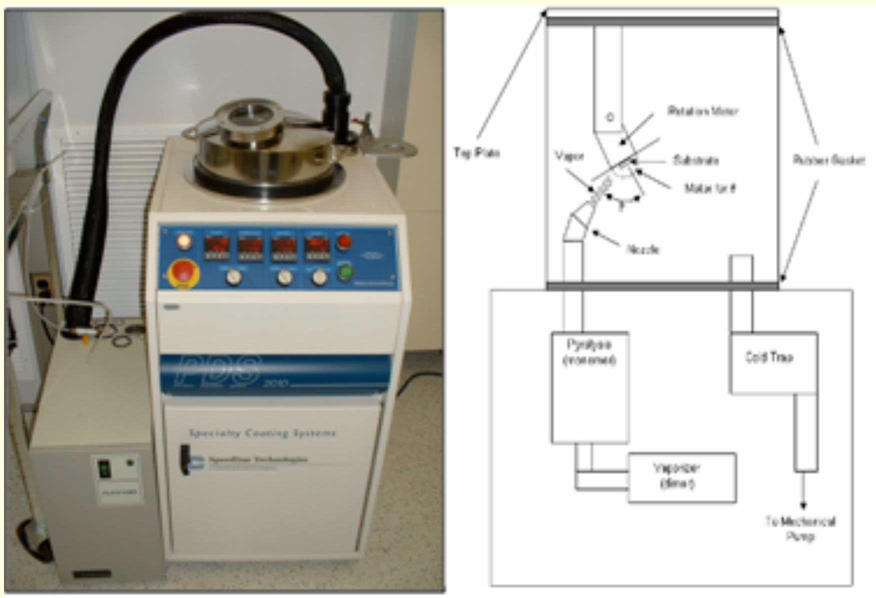
Polymer Communication

Growth of sculptured polymer submicronwire assemblies by vapor deposition

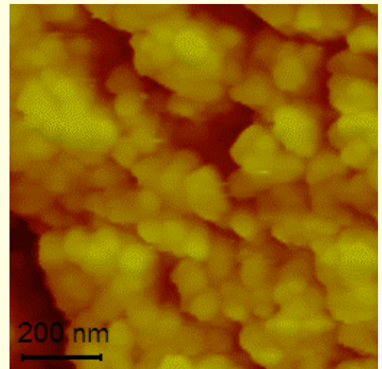
Sean Pursel, Mark W. Horn, Melik C. Demirel*, Akhlesh Lakhtakia

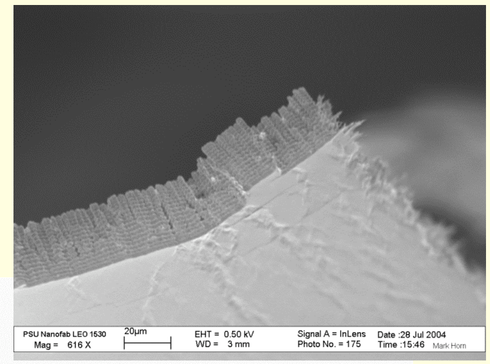
First, pyrolize to monomer state, and then deposit

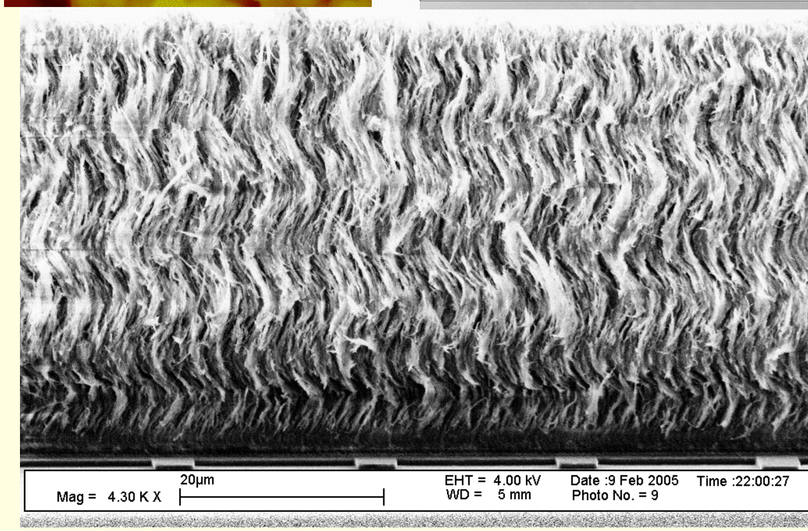
POLYMERIC STFs:
COMBINED CVD+PVD TECHNIQUE



The PDS 2010 system and the schematic of stepper motor and nozzle assembly used with the polymer deposition system.







POLYMERIC STFs:
HOLOGRAPHIC LITHOGRAPHY

ELSEVIER

Available online at www.sciencedirect.com

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PHOTONICS AND NANOSTRUCTURES
Fundamentals and Applications

Photonics and Nanostructures – Fundamentals and Applications 3 (2005) 79–83

www.elsevier.com/locate/photonics

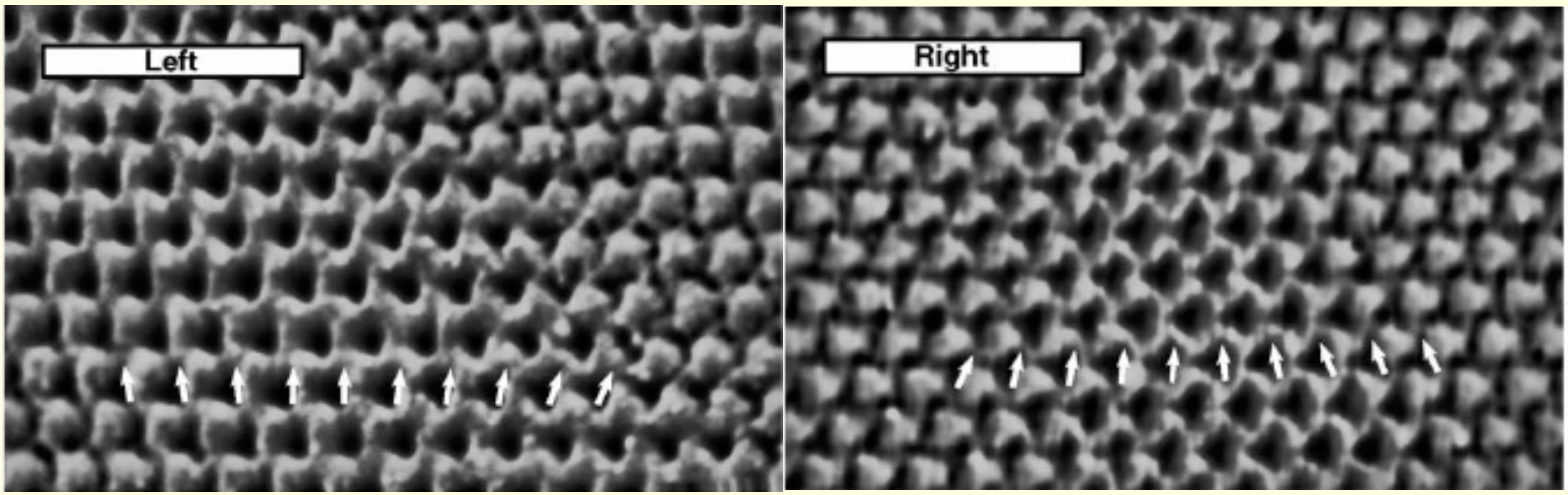
Photonic crystals with a chiral basis by holographic lithography

E.R. Dedman [a], D.N. Sharp [a,*], A.J. Turberfield [a], C.F. Blanford [b], R.G. Denning [b]

1. 4-laser beams to expose photoresist
   (1 beam should be elliptically polarized)

2. Develop the exposed photoresist layer

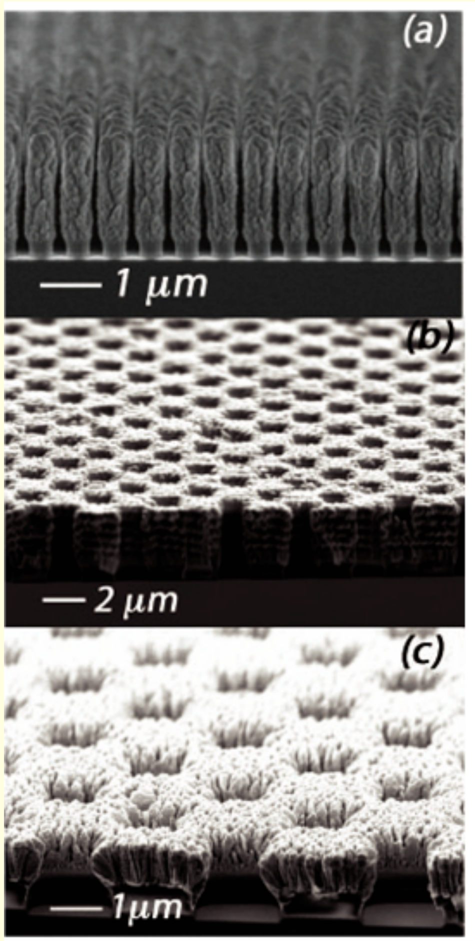
POLYMERIC STFs:
HOLOGRAPHIC LITHOGRAPHY



Photonic Crystals vs. STFs

5. BIOSCAFFOLDS

BIOSCAFFOLDS

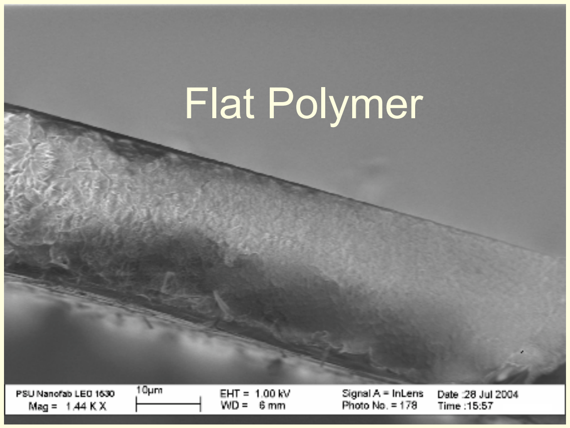


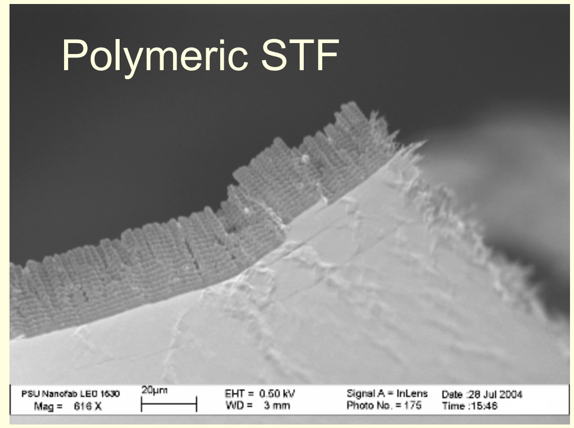
Horn, M.W., Pickett, M.D., Messier, R., Lakhtakia, A., NANOTECHNOLOGY, Vol. 15, pp. 303-310, 2004

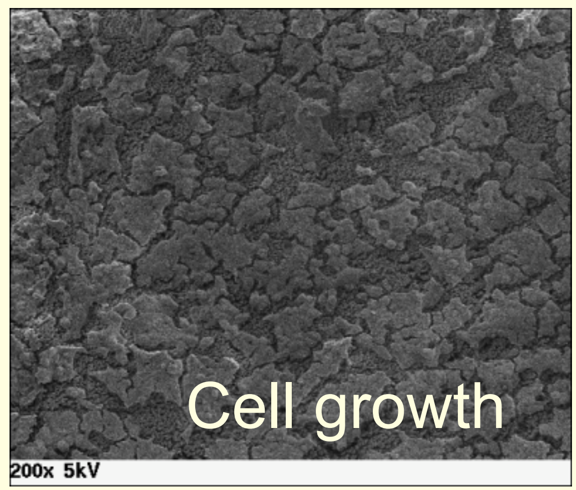
The three advantages of STFs are as follows:

1. **Surface-to-volume ratio is very high in STF films (> two orders of magnitude).**
2. **STFs can be made out of virtually any material and can be endowed with transverse architectures to provide the best possible substrates for attachment at the nanoscale.**
3. **Optical properties suitable for sensing.**

BIOSCAFFOLDS



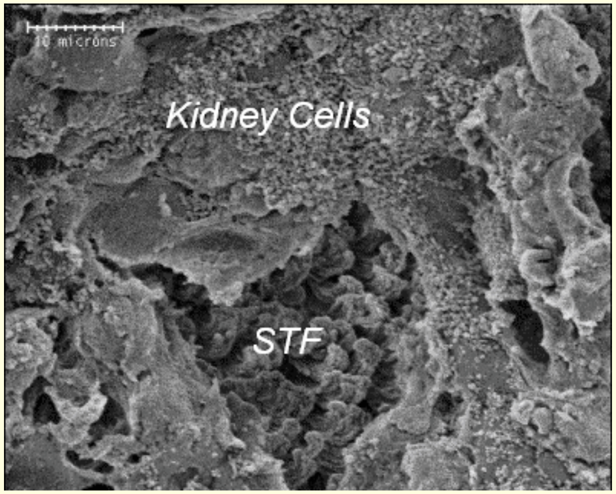




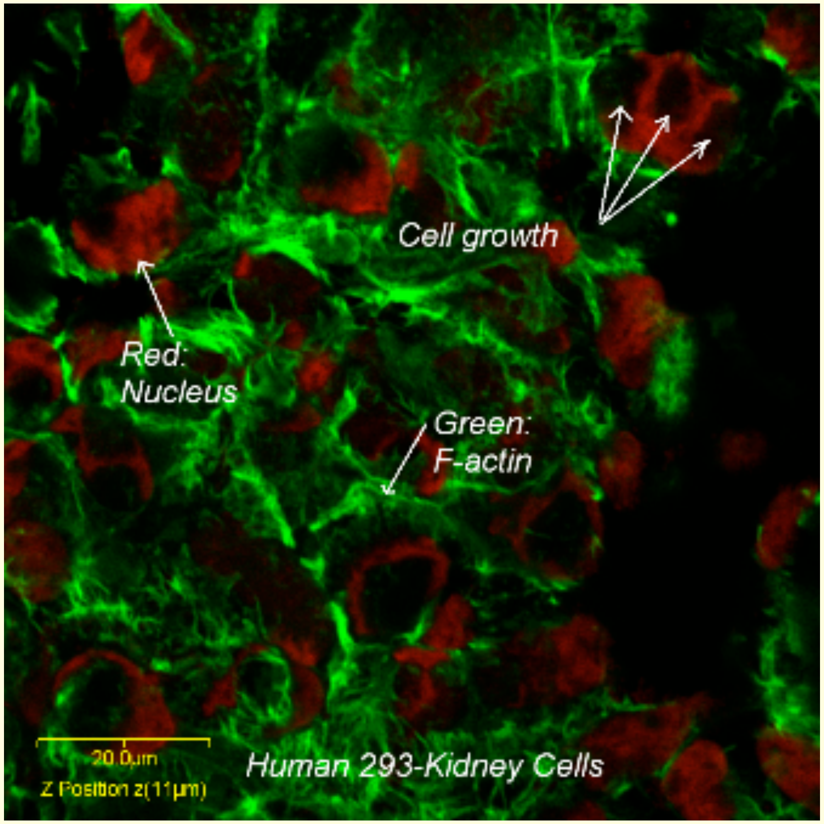
Cells grow, but detach

Cells grow, and attach

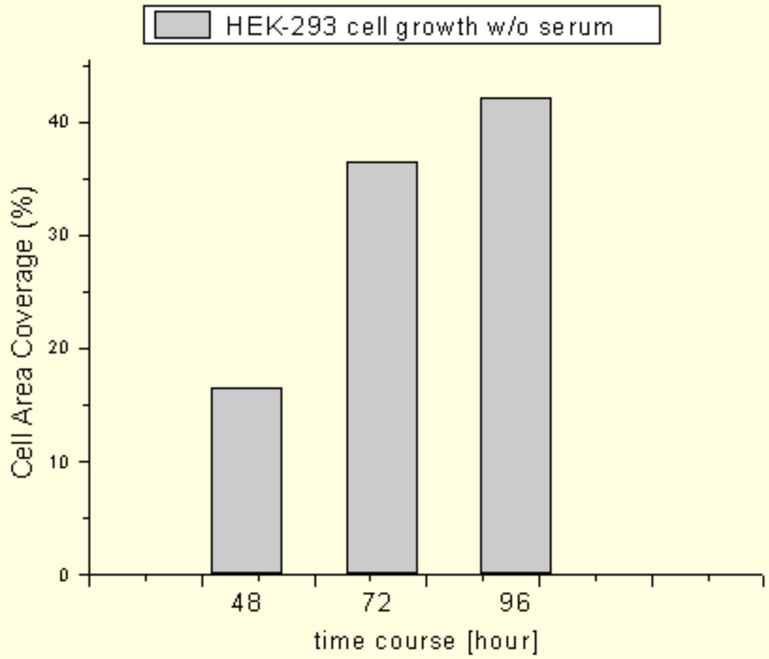
BIOSCAFFOLDS



BIOSCAFFOLDS



BIOSCAFFOLDS

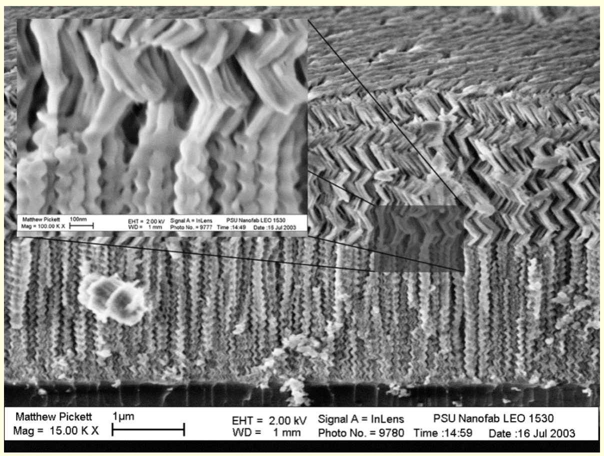


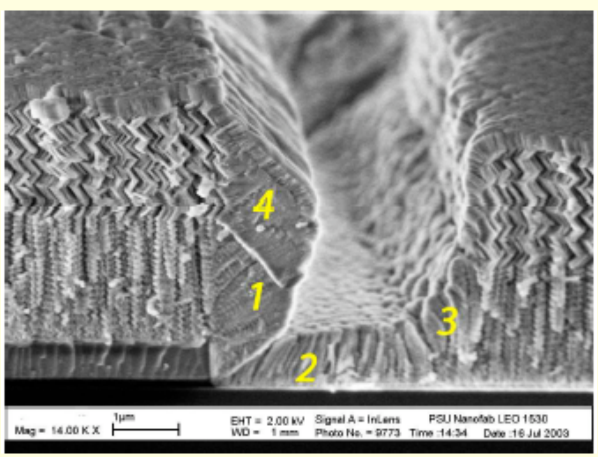
6. STFs WITH TRANSVERSE ARCHITECTURE

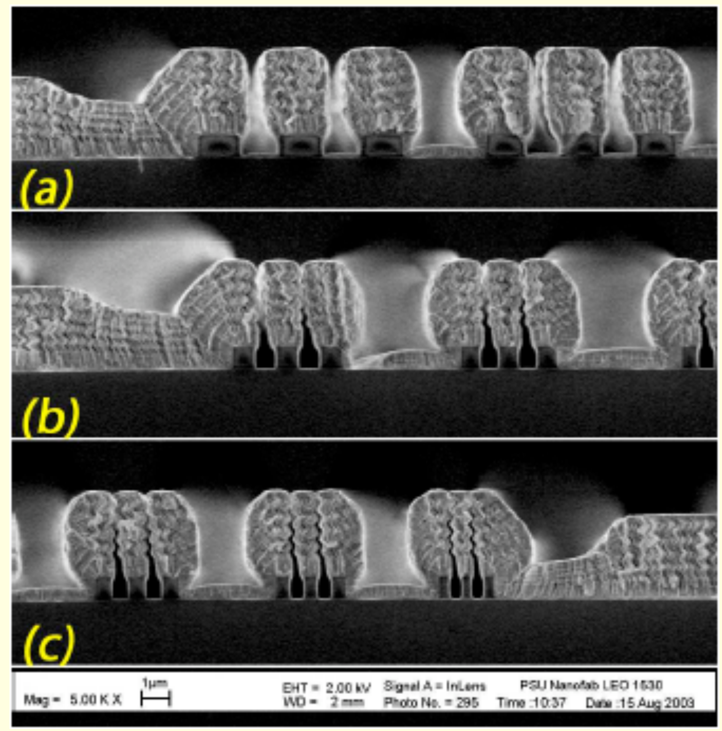
STFs WITH TRANSVERSE ARCHITECTURE

STFs on Microscale Topography

(Cross-sectional SEMs of SiOx STFs)

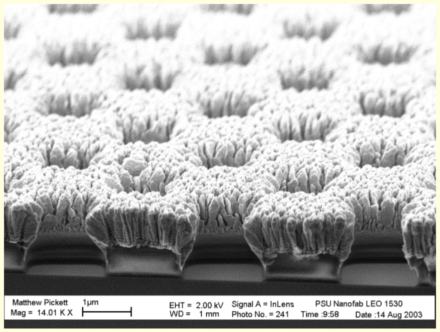




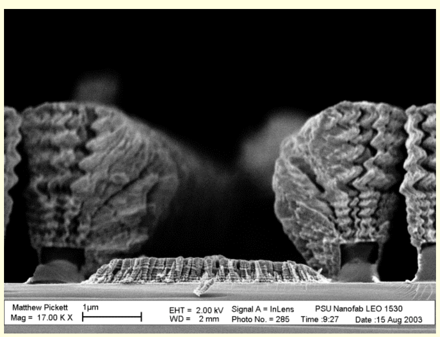


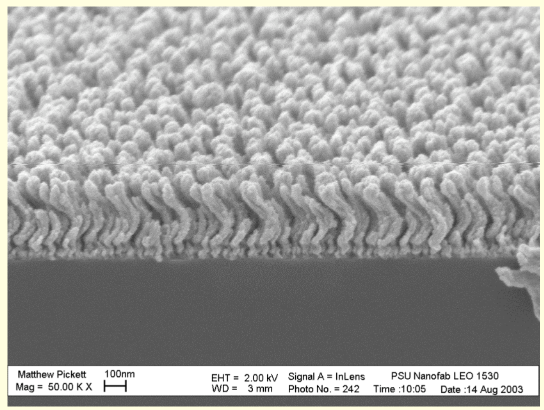
STFs WITH TRANSVERSE ARCHITECTURE

Metal STFs on Topography

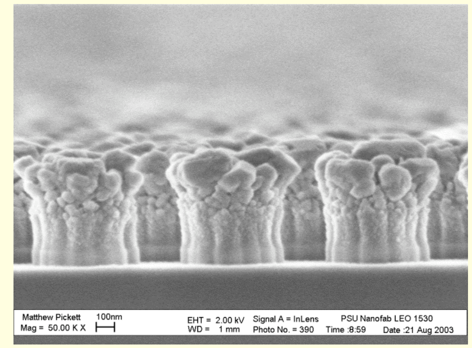


Chromium

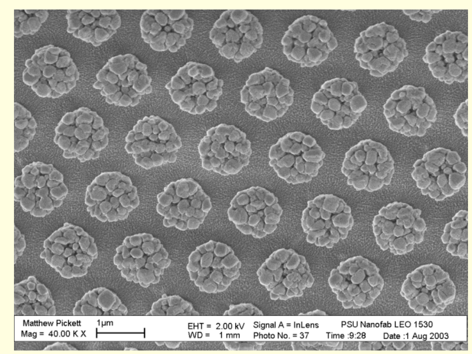




Molybdenum

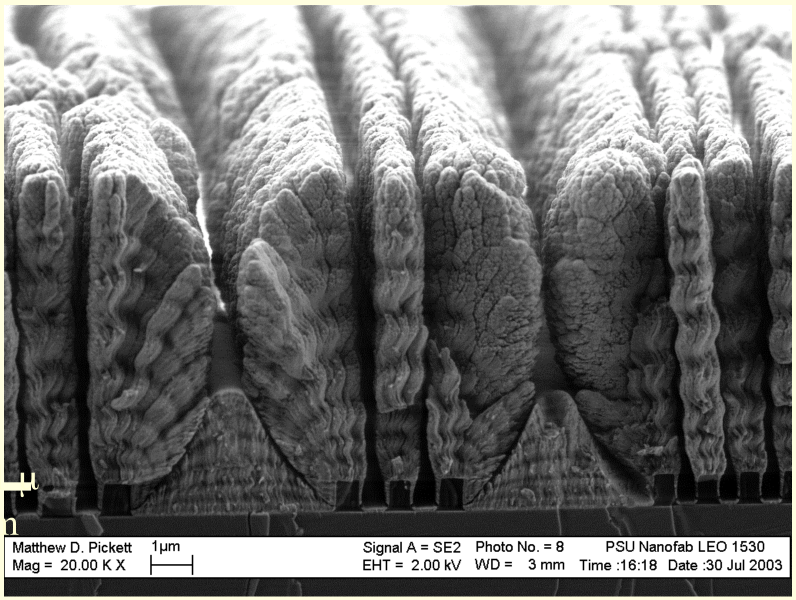


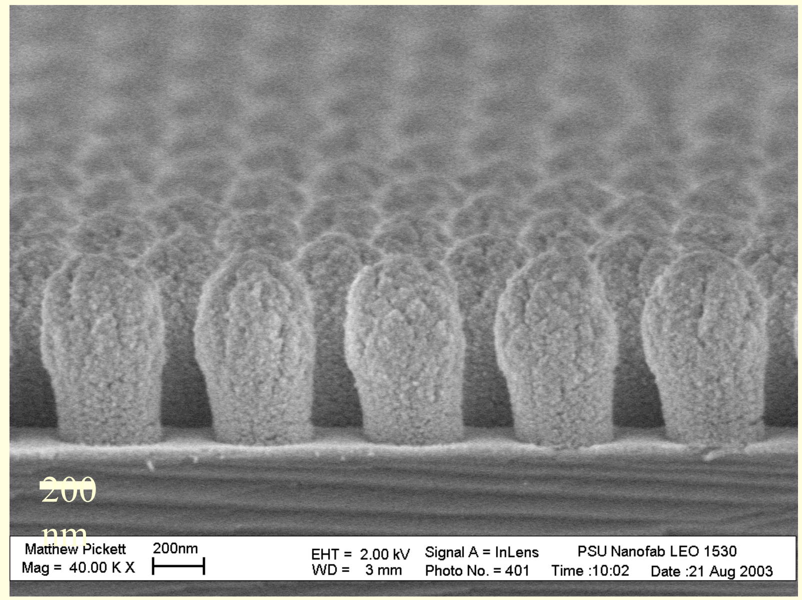
Aluminum



STFs WITH TRANSVERSE ARCHITECTURE

Semiconductor STFs on Micro and Nanoscale Topography

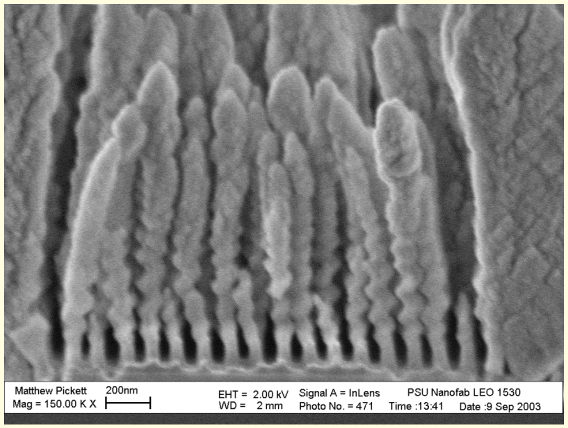




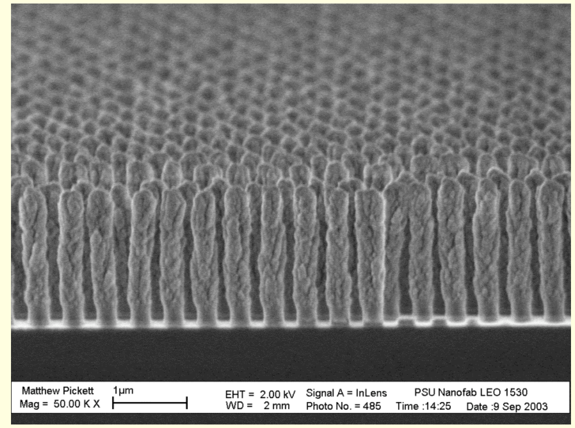
SnO_x STFs grown on photoresist patterns

STFs WITH TRANSVERSE ARCHITECTURE

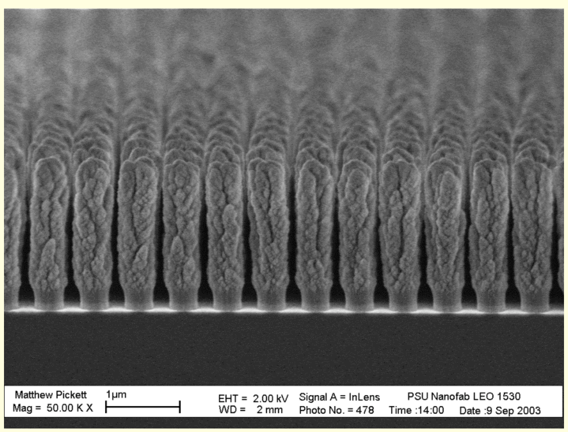
Sculptured Nanowires on Nanoscale Topography



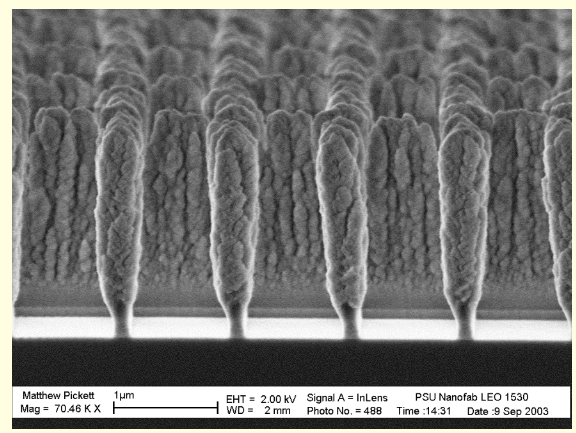
Single SiOx nanowire array grown on 60 nm e-beam resist



HCP array of SiOx nanocolumns



BCC array of SiOx nanocolumns



1um x 1um mesh of SiOx nanolines

STFs WITH TRANSVERSE ARCHITECTURE

INSTITUTE OF PHYSICS PUBLISHING NANOTECHNOLOGY
Nanotechnology 15 (2004) 303–310 PII: S0957-4484(04)69259-2

Blending of nanoscale and microscale in uniform large-area sculptured thin-film architectures

Mark W Horn, Matthew D Pickett, Russell Messier and Akhlesh Lakhtakia[1]

Selective growth of sculptured nanowires on microlithographic lattices

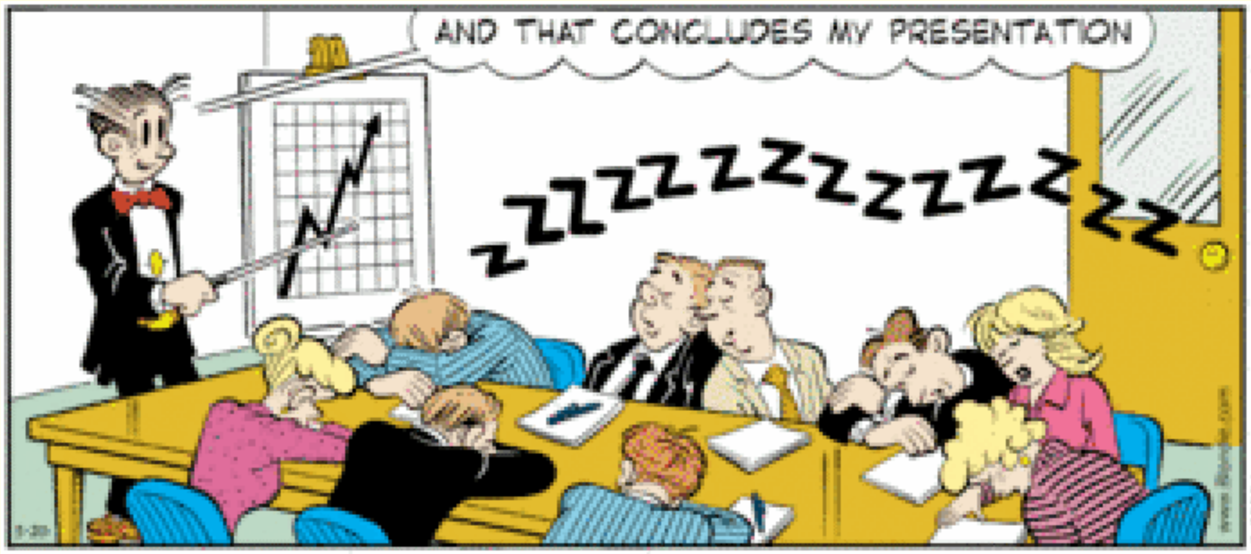
Mark W. Horn,[a)] Matthew D. Pickett, Russell Messier, and Akhlesh Lakhtakia
Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, Pennsylvania 16802

(Received 25 June 2004; accepted 4 October 2004; published 14 December 2004)

We have grown helicoidal nanowire assemblies on a variety of topographic substrates with regular microlithographic patterns, thereby demonstrating that sculptured thin films with transversely latticed architecture can be grown by physical vapor deposition. The transverse feature-separations are as low as 100–300 nm, and mesa regions are circular posts as small as 60 nm in diameter. The initial as well as the subsequent stages of growth on topographic substrates can be understood using simple geometric shadowing arguments. *© 2004 American Vacuum Society.*

Emerging Directions

- Light Emitters
- STFs with Gain
- Electrically Controlled STFs
- Polymeric STFs
- Bioscaffolds
- STFs with Transverse Architecture



Muchas gracias