THz Resonances in Chiral Aluminum Nanowires

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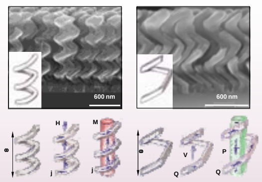
Our Message

- glancing angle deposition used to grow sculptured thin films composed of achiral and chiral aluminum wires
- ellipsometric measurements of chiral nanowires in the far- and midinfrared spectral domain reveal equally spaced resonances with $\Delta\nu \sim 7.5$ THz
- a first approach interprets THz resonances using a simple LC model
- Mueller matrix mapping in the NIR spectral range allows immediate determination of symmetry of the nanostructures

Properties of Sculptured Thin Films

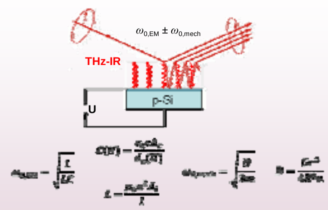
Sculptured Thin Films



E. Schubert *et al.*, Appl. Phys. A **81**, 481 (2005).
E. Schubert *et al.*, Nucl. Instr. Meth. B **244**, 40 (2006).

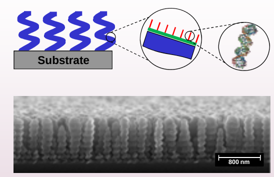
ion beam assisted deposition can be used to grow metamaterials composed of self-organized nanostructures with a wide variety of shapes and different semiconductors or metals

New Resonator Structures



- nanowires might have tunable opto-mechanical resonances in the THz frequency domain
- new detector and source concepts
- new opto-mechanical sensor designs

New Bio-molecular Detectors

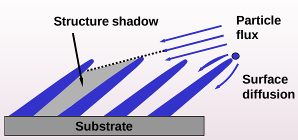


- principle of functionalized chiral nano-structure surfaces
- chiral nanostructures functionalization by surface hydroxylation, silanization, and peptide attachment

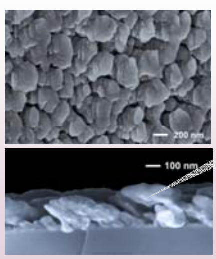
Guha-Thakruta and Subramanian, J. Electrochemical Soc., in print

Glancing Angle Deposition of Aluminum Nanowires

Achiral STF



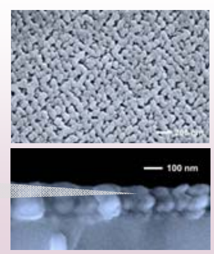
The incoming particle flux at glancing angle causes self-organized columnar growth due to shadowing and slow surface adatom movement.

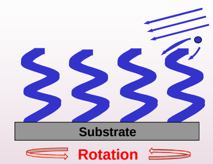


Growth of slanted columnar aluminum structures for fixed substrate orientation during GLAD

Vertical aluminum screws are grown while performing continuous substrate rotation during GLAD

Chiral STF



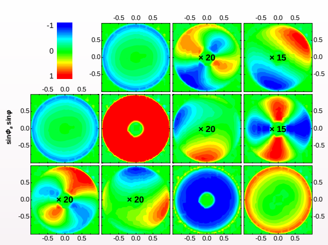


Growth of nanospirals is achieved while the substrate is rotated around its normal during deposition process.

Optical Response of Aluminum Nanowires

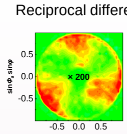
NIR Mueller Matrix Mapping

Achiral STF



Mueller matrix map (azimuthal rotation φ and angle of incidence scan Φ_a) @ λ = 1550 nm; anisotropic optical response: elements M_{13}, M_{31}, M_{32}, M_{23}, M_{i4} are not zero!

Reciprocal difference



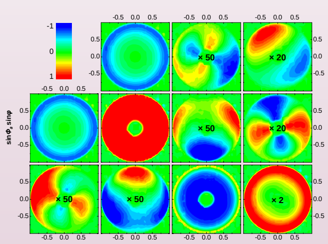
Non-zero reciprocal difference ($M_{13}(\varphi)$ + $M_{31}(\varphi+\pi)$) hints to the existence of bi-anisotropic material properties and 3-fold symmetry of the STF.

Mueller matrix descriptor

$$\begin{pmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ & \text{not yet measured} & & \end{pmatrix}$$

- M_{13} isotropic p-s conversion axes
- M_{14} iso-chiral axes
- M_{24} iso-chiral birefringence axes
- M_{31} generalized Brewster condition; incident unpolarized light is either p- or s- polarized with ellipticity

Chiral STF



Mueller matrix map (azimuthal rotation φ and angle of incidence scan Φ_a) @ λ = 1550 nm; anisotropic optical response: elements M_{13}, M_{31}, M_{32}, M_{23}, M_{i4} are not zero!

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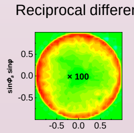
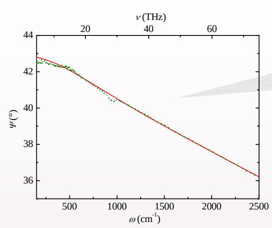


Non-zero reciprocal difference ($M_{13}(\varphi)$ + $M_{31}(\varphi+\pi)$) hints to the existence of bi-anisotropic material properties and reflects the continuous screw shape of the STF.

D. Schmidt, E. Schubert, and M. Schubert, phys. stat. sol. (a) **205**, 748 (2008).

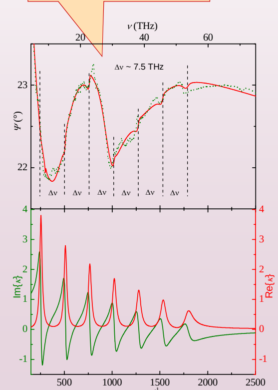
Infrared Ellipsometry



Achiral STF shows simple Drude-like behavior. Best fit values for resistivity and scattering time are ρ = 10.9·10^{-5} Ωcm and τ = 1.0 fs, respectively.

Comparison with aluminum bulk values
Bulk: ρ = 0.29·10^{-5} Ωcm, τ = 6.7 fs
STF: ρ = 10.9·10^{-5} Ωcm, τ = 1.0 fs

Equidistant resonances!



First model approach: THz resonances interpreted as harmonics of a LC resonator (coil + Schottky barrier capacitor)

Effective multiple harmonics generation predicted
B.L. Gelmont, D.L. Woolard, T.W. Crowe, R.J. Mattauch, Phys. Rev. B **61**, 15939 (2000).

Constitutive relations for bi-anisotropic materials:

$$\mathbf{D} = \bar{\bar{\varepsilon}} \cdot \mathbf{E} + \sqrt{\varepsilon_0 \mu_0}(\bar{\bar{\chi}} - j\bar{\bar{\kappa}}) \cdot \mathbf{H}$$
$$\mathbf{B} = \bar{\bar{\mu}} \cdot \mathbf{H} + \sqrt{\varepsilon_0 \mu_0}(\bar{\bar{\chi}} + j\bar{\bar{\kappa}}) \cdot \mathbf{E}$$

$\bar{\bar{\kappa}}$ chirality parameter
$\bar{\bar{\chi}}$ non-reciprocity parameter

THz resonances modeled using Lorenzian lineshapes in the chiral tensor components + Drude-like isotropic dielectric background

STF: ρ = 120·10^{-5} Ωcm, τ = 0.6 fs

Achievable frequencies by changing resonator parameters

A (cm^2)	l (µm)	N	d (nm)	L (Vs/A)	C (As/V)	ν (THz)
4×10^{-10}	2.50	10	100	8×10^{-12}	3.5×10^{-18}	29.0
			10		3.5×10^{-17}	9.0
			5		7.0×10^{-17}	6.7
	1.25	5	10	1×10^{-12}	3.5×10^{-17}	27.0
			5	1×10^{-12}	7.0×10^{-17}	19.0