Metal Sculptured Thin Film THz Optical Sensors

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Our Message

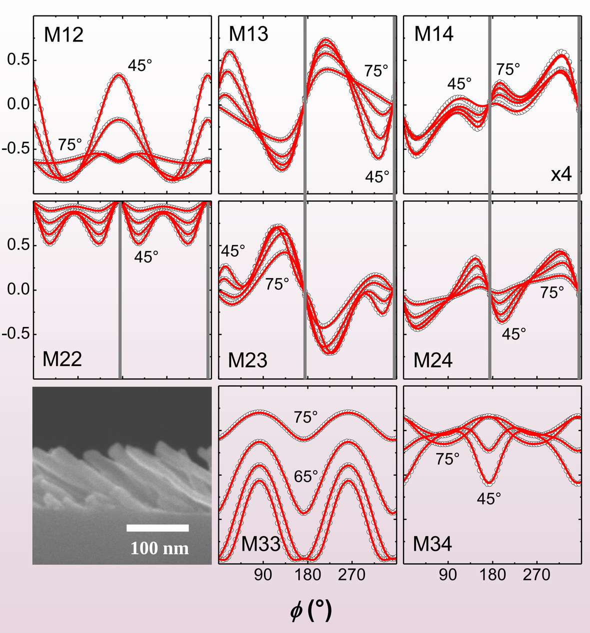
- The complex anisotropic THz optical response of Cobalt columnar sculptured thin films (STFs) can be determined precisely using spectroscopic ellipsometry (SE).
- An anisotropic Bruggeman effective medium approach allows accurate analysis of the THz-SE data.
- The use of THz transparent substrates enhances the STF optical fingerprint.
- The changes in the host (ambient) medium permittivity can be accurately monitored – metal STFs can serve as a building block for future THz biochemical sensor applications.

STF THz Optical Sensors

Optical Response of Metal STFs

- STF's show distinct optical anisotropy in VIS spectral range (D. Schmidt et al., J. Appl. Phys. **105**, 113508 (2009))
- Dramatic changes have been observed upon ambient changes in the VIS spectral range

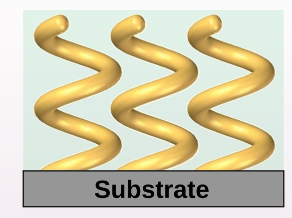
THz spectral response and effects upon ambient changes are unknown!



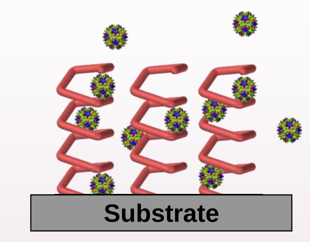
λ = 630 nm

THz Sensor Concept

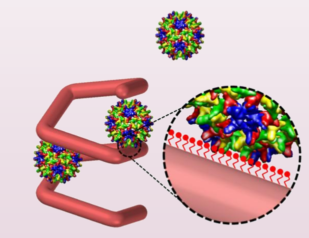
Detection of Liquids:



Detection of Bio-molecules:



- Minute amounts of liquids are detectable due to the changes in the STF optical response
- Surface functionalization allows selective detection of biomolecules and their THz optical properties

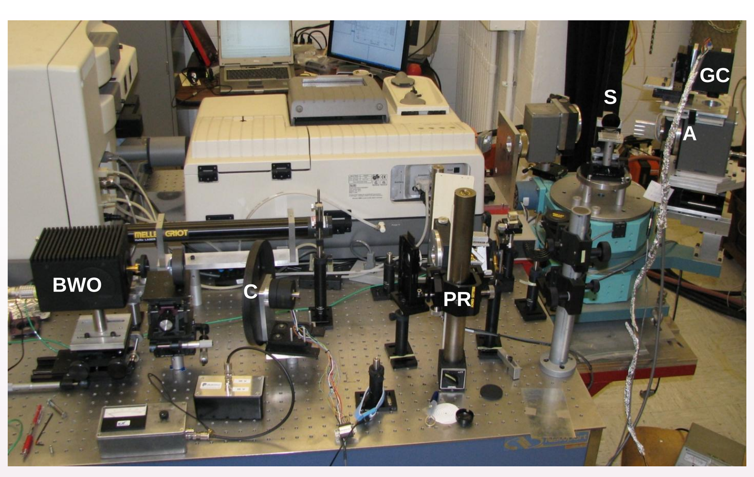


Nanohybrid functional materials for the THz frequency domain!

Experimental Setup and Sample Preparation

Generalized THz Ellipsometry

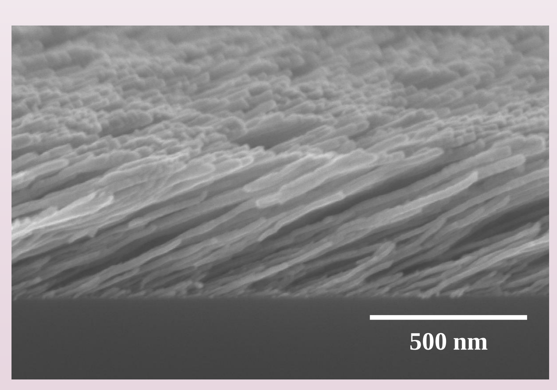
- rotating analyzer ellipsometry configuration
- achromatic (THz-MIR) polarization rotator (PR) to manipulate the input polarization state
- backward wave oscillator (BWO) source
- Golay cell detector (GC)



Hofmann *et al.*, Rev. Sci. Instrum. 81, 023101 (2010)

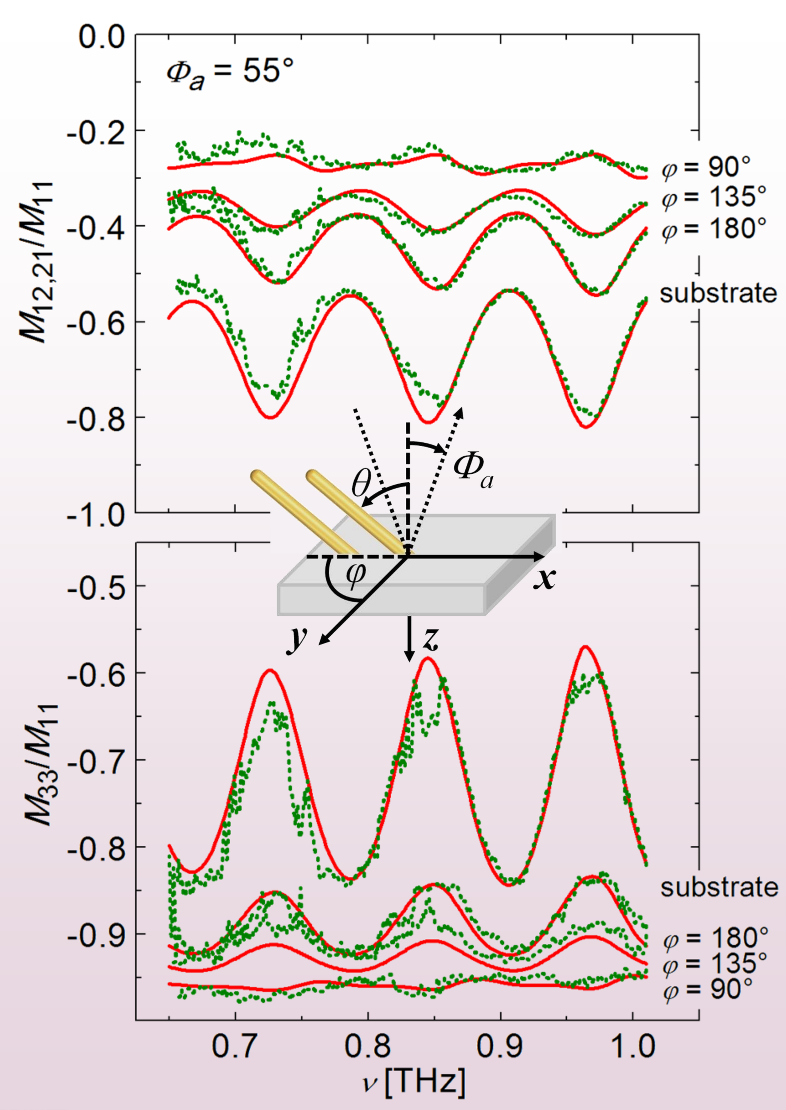
Co STF Sample Preparation

- custom electron-beam glancing angle deposition of Cobalt sculptured thin films
- 85° incident particle flux with respect to the substrate normal
- low doped, double-side polished Si substrate
- no substrate rotation during deposition results in a slanted nanocolumnar STF
- nominal film thickness is 450 nm with a 65° slanting angle

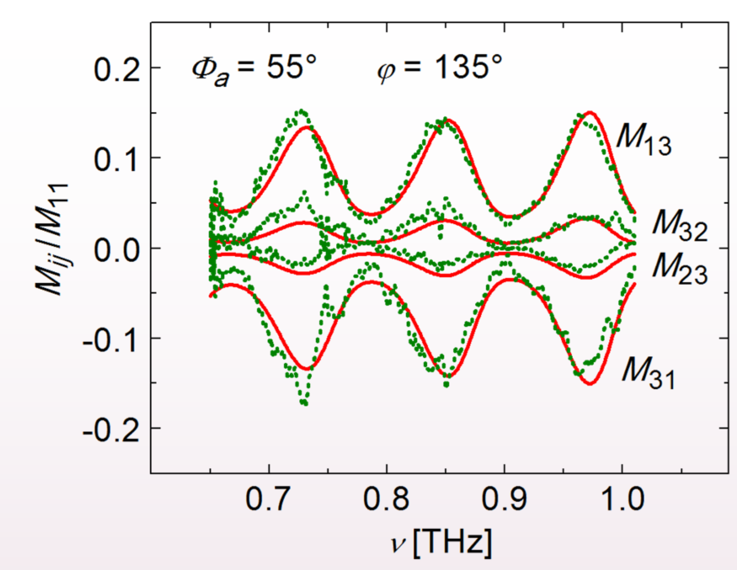


SEM micrograph (sample tilted 15°) of the Co STF

THz Dielectric Anisotropy of Co STFs



Hofmann *et al.*, Appl. Phys. Lett. **99**, 081903 (2011)



Right: Experimental (green lines) and best-model calculated (red lines) off-diagonal Mueller matrix spectra for the Co STF sample for an in-plane rotation angle φ = 135°.

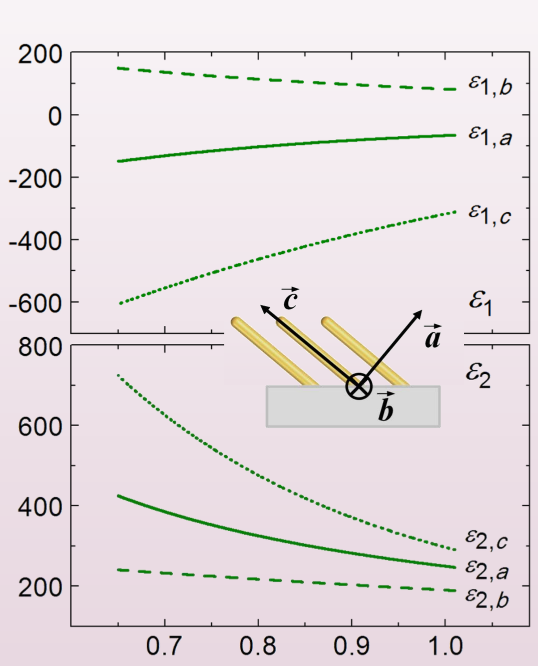
Left: Mueller matrix spectra for a Co STF sample for three different in-plane rotation angles φ = 90°, 135°, and 180°. The spectra for the silicon substrate before Co STF deposition are shown for comparison.

Effective Medium Approach

Anisotropic Bruggeman EMA

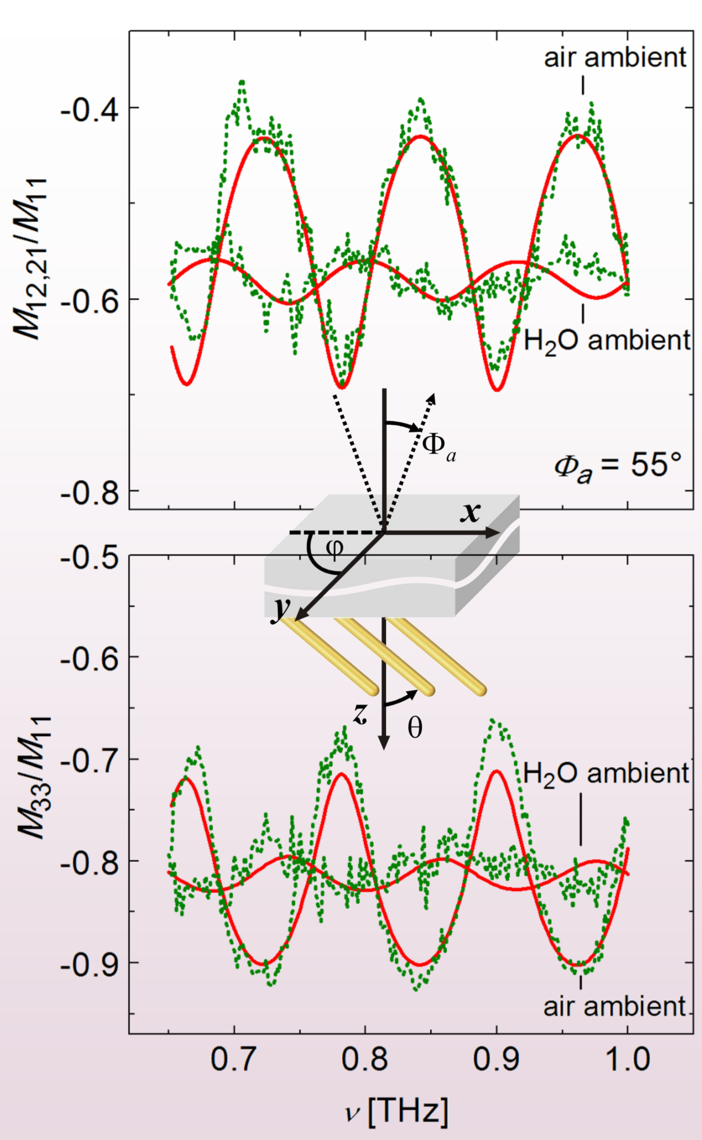
$$\varepsilon_j = \varepsilon_m + \frac{f(\varepsilon_i - \varepsilon_m)\varepsilon_j}{\varepsilon_j + L_j(\varepsilon_i - \varepsilon_j)}$$

- ε_j anisotropic Bruggeman EMA dielectric function tensor components along the major axes $j = a, b, c$
- ε_m host medium permittivity
- ε_i permittivity of the nanocolumnar inclusions
- f volume faction of the nanocolumnar inclusions
- L_j depolarization factors with $L_a+L_b+L_c=1$

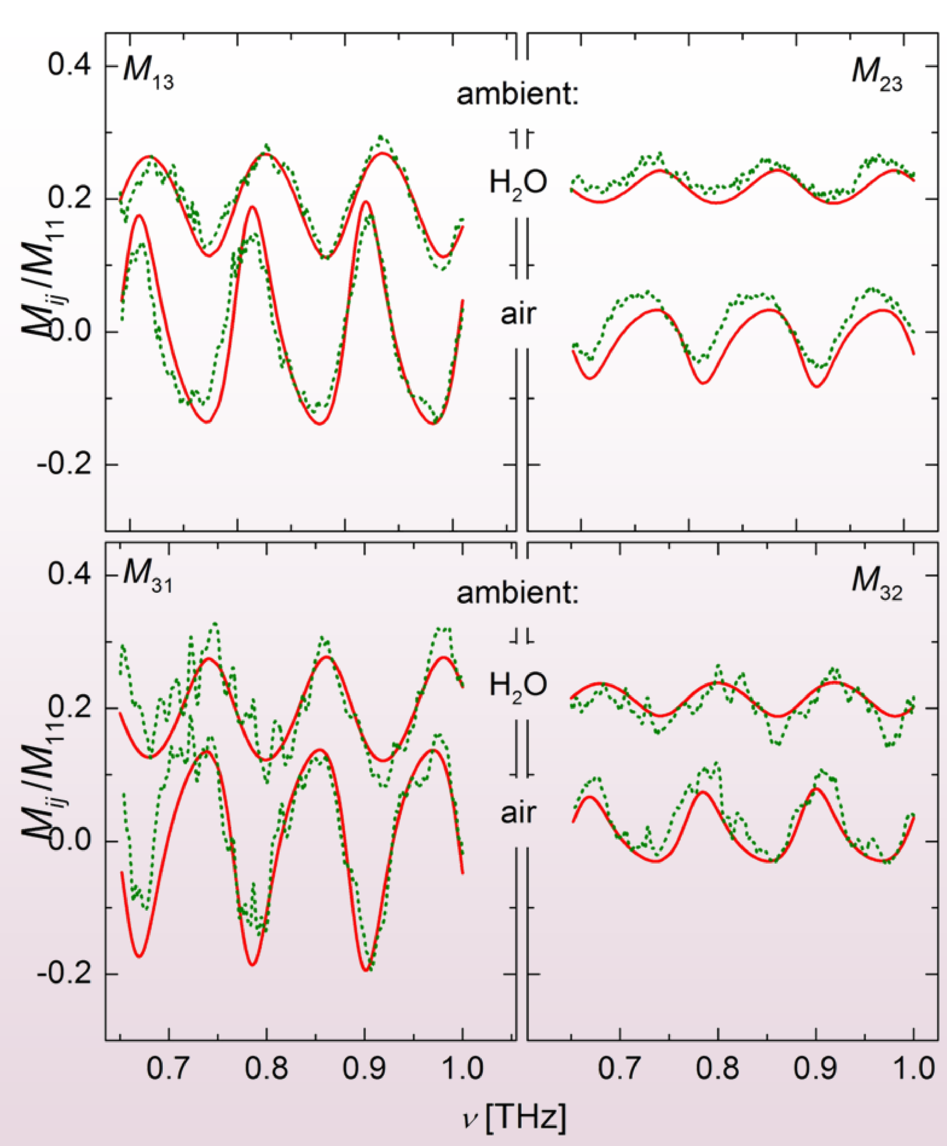


Real $\varepsilon_{1,a}$, $\varepsilon_{1,b}$, and $\varepsilon_{1,c}$ and imaginary $\varepsilon_{2,a}$, $\varepsilon_{2,b}$, and $\varepsilon_{2,c}$ part of the THz orthorhombic dielectric functions obtained from the best-model calculation of the Co STF sample.

Cobalt Sculptured Thin Films in Aqueous Environment

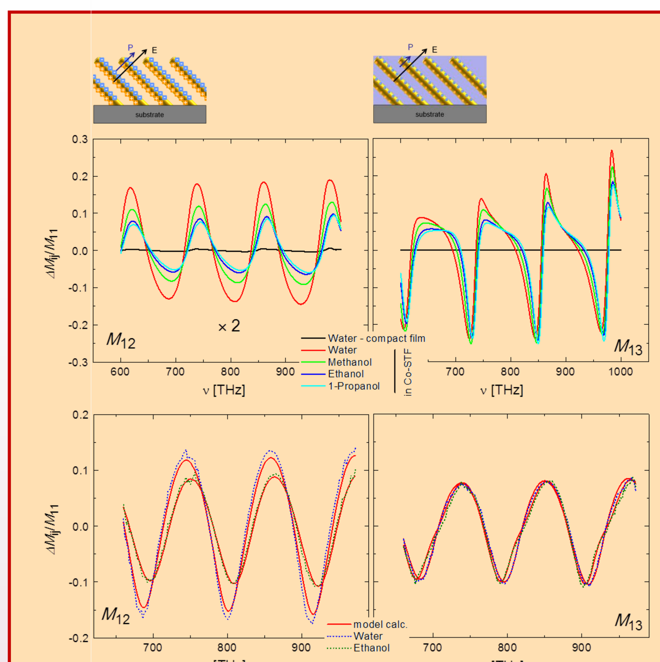


Mueller matrix spectra obtained for the Co STF sample in air and water ambient. The in-plane rotation angle was φ = 225°. Note that the THz probe beam illuminates the backside of the sample as shown in the inset.



Off-diagonal Mueller matrix spectra obtained for the Co STF sample in air and water ambient for the in-plane rotation angle φ = 225°. Note that the spectra obtained for water ambient are shifted by 0.2.

THz Optical Sensor Respose



Calculated Mueller matrix (M_{13}) difference spectra obtained by calculating the difference between M_{13} obtained for the STF in water ambient and M_{13} obtained for the STF in a test ambient.

The test ambient is identical to water (described by the commonly used Debye relaxation) except for a constant offset in the permittivity $\delta\varepsilon_{\mathrm{off}}$.

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