Terahertz ellipsometry using electron-beam based sources

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MoP.99

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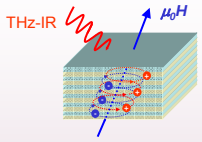
Our message

- **THz ellipsometry opens a new pathways for the investigation of the properties complex optical materials needed as building blocks for next generation nanoelectronics**
- **in combination with external magnetic fields THz generalized ellipsometry is a powerful tool to determine free charge carrier properties and study quantum confinement effects in semiconductors and semimetals**
- **electron beam based sources are readily available (Synchrotron radiation, Smith-Purcell radiation) and offer sufficient radiation in the THz frequency domain**

New THz materials preparation and analysis Center at UNL: THeMPAC

Motivation: THz spectroscopic ellipsometry

2D Semiconductor & Semimetal

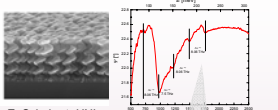


quantum confinement-effects in low dimensional systems

Generalized ellipsometry in combination with external magnetic fields:

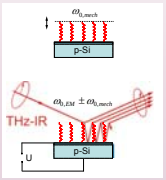
- Semiconductors: unbound charge carrier resonances in spatially confined structures in the THz frequency domain
- Highly oriented pyrolytic graphite: Landau level transitions, electron and hole contributions

Complex metamaterials



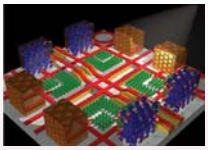
E. Schubert, UNL

resonances in a sculptured Al thin Film on Si



new detector structures: quantum opto-mechanical couplers with Eigenresonances in the THz-IR domain

3D Nanostructure Networks



D. E. Scharett and R. E. Garrison Arm. Log. **37** (2005)

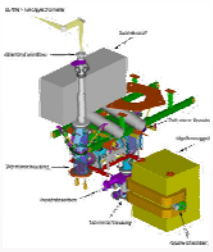
- future nanoelectronics will be assembled from nano-sized thin film structures and metamaterials
- new physical phenomena in these building blocks like quantum confinement and surface effects will alter the physical properties and need to be studied

optical metrology tools needed

optical and mechanical Eigenresonances of these material fall in the THz domain

Synchrotron radiation

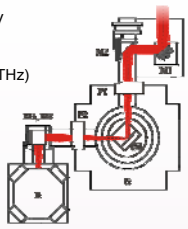
IRIS-beam line at BESSY II



- electron energy of 1.7 GeV
- beam current ~300 mA
- λ= ~30 to 3000 cm^{-1} (333 to 3 25 μm, 0.9 to 90 THz)

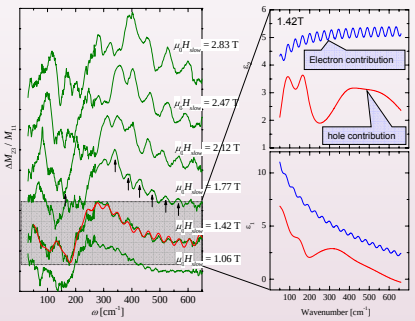
W.B. Peatman and U. Schade, Rev. Scie. Inst. **72**, 1620 (2001)
U. Schade et al. Rev. Scie. Inst. **73**, 1563 (2002)

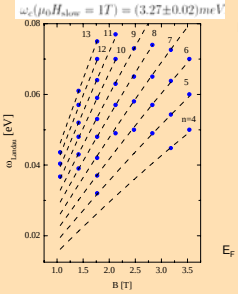
Experimental setup



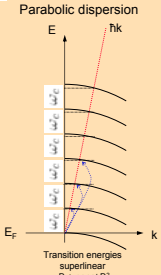
T. Hofmann et al. Rev. Scie. Inst. 77, 63902 (2006)

Highly oriented pyrolytic graphite





Parabolic dispersion



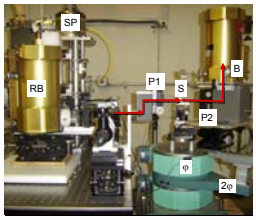
$$\hbar\omega_{Landau} = \hbar\omega_c(\nu + \mu_0), \nu = 1, 2, \ldots$$
$$\mu_0 = 0.849 \pm 0.006$$
$$\omega_c \approx \frac{e\mu_0 H}{m(1 + \beta\mu_0 H)}$$
$$\beta = (0.034 \pm 0.002)T^{-1}$$
$$m = 0.0354 \pm 0.0002$$

Field dependence: relativistic mass increase?
Offset: Graphite zero-point energy?

Conclusion: Landau transitions should originate from unoccupied valence band states!

Smith-Purcell free electron laser

Smith-Purcell effect



Smith-Purcell Source:

- electron energy: 20-38 keV
- grating type: rectangular Cu-grating (25 μm wide, 100 μm deep slots)

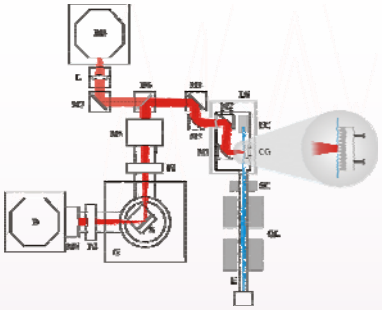
Electromagnetic radiation is emitted if an electron beam passes a periodic metal grating:

S.J. Smith and E.M. Purcell Phys. Rev. 92, 1069 (1953)
J. Urata et al. Phys. Rev. Lett. 90,516 (1998)

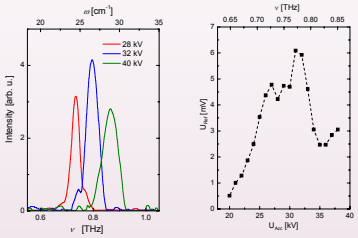
$$\lambda = \frac{L}{|n|}\left(\frac{1}{\beta} - \sin\theta\right)$$

λ – output wavelength
βc – electron velocity
θ – emission angle

Experimental setup



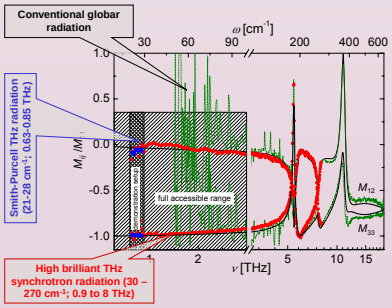
T. Hofmann et al. Rev. Scie. Inst. (in submission)



typical output intensity spectra and signal level at the reference Si-Bolometer; the source is operated below the threshold to superradiant emission

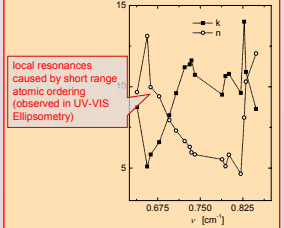
$Zn_{0.87}Mn_{0.13}Se$

ZnMnSe – a diluted magnetic semiconductor is employed as an example system



T. Hofmann et al. Appl. Phys. Lett. 77, 63902 (2006)

First optical constants for ZnMnSe in the THz domain!



Higher resolution measurements needed!

4th International Conference on Spectroscopic Ellipsometry, Stockholm, June 11-15 2007

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