Maxim Khazan

Darstellung der Forschungsaktivitäten

The terahertz (THz) frequency range is of particular interest for the fundamental superconductor materials science since it covers quasiparticle scattering rates [R. Mallozzi et al., J.Phys.Chem. Solids, **59**, 2095 (1998)]. Furthermore, the success of the application of high-Tc superconducting (HTS) thin films in microwave electronic devices now stimulates research on high-Tc superconducting devices operating at THz frequencies [M. J. Lancaster, Cambridge: University Press, 1997; M. A. Hein, in Springer Tracts in Modern Physics vol. 155, G. Höhler, Ed., Heidelberg: Springer, 1999]. Commonly, superconductors in high-frequency fields are characterized by surface resistance and penetration depth which can be measured by means of time-domain THz spectroscopy. In electronic applications, materials are usually employed in form of thin films rather than in bulk form. Properties of thin films can differ significantly from those of bulk material mainly due to the higher concentration of defects. The dominating defect in HTS thin films are grains which are usually up to few micrometer in size. So, structured thin films with the pattern size of tens to hundreds nanometer could be expected to exhibit the behavior different from solid films.

Time-domain THz spectroscopy (TDTS) is a relatively new measurement technique so there are no commercially available time-domain THz spectrometers which would have the parameters required for superconductors research. The spectrometer that we have built has the following performance: frequency range 0.1 - 1.6 THz, temperature range 25 - 300 K and signal-to-noise ratio larger than 2000.

The main goal of this doctoral project is to study superconducting thin films in the frequency range from 100 GHz to 1.5 THz at temperatures well below Tc. We are particularly interested in materials that are perspective in technical applications but whose characteristics are rather unexplored in THz range e.g. TlBaCaCuO- and BiSrCaCuO-systems. Also, c-axis electrodynamics of cuprate superconducting thin films (including YBCO) still has not been properly studied.

Unlike, for example, most of microwave spectroscopic methods that only give the surface resistance of a sample, the TDTS provides direct access to the complex dielectric function (or conductivity) of the material under study so that no a priori assumptions about the material's nature have to be made. Previously, the complex conductivity had been extravted from transmission data by using the thin-film approximation had been used. But in the case of HTS films high values of the index of refraction make this approximation hardly applicable. Instead, we have elaborated a new procedure of the numerical solving of the transmission equation which liberates us from such limitations [I. Wilke, M. Khazan, C.T. Rieck, P. Kuzel, T. Kaiser, C. Jaekel and H. Kurz, J. App. Physics **87**, 2984 (2000)]. Some effects that are hard to see on surface resistance spectra can be clearly observed in frequency dependencies of the dielectric function. Thus, in dielectric spectra of $YBa_2Cu_30_{6.95}$ thin films a pronounced

resonance has been discovered [Wilke, M. Khazan, C.T. Rieck, P. Kuzel, T. Kaiser, C. Jaekel and H. Kurz, Physica C, 2000 (in press)]. The nature of the resonance is currently under investigation. It is thought to be the interplay of the parent compound phonons observed in $YBa_2Cu_3O_6$ [Z. Zhai, P. Parimi, J. Sokoloff, S. Sridhar, A. Erb, submitted to PRL] and Josephson plasma resonance. The last is assumed to take place between grains in the superconducting film.

Another HTS material that is currently under study in our THz laboratory is $Tl_2Ba_2CaCu_2O_8$ (Tl-2212). For the first time we have measured the surface resistance of the material in the frequency range from 200 GHz to 1.0 THz at temperatures from 25 to 300 K. Our results show that Tl-2212 films can be used in THz electronics with at least the same effectiveness as YBCO and thank to their higher Tc and lower 1/f noise [M. N. Eddy, J. Z. Sun, R. D. Hammond, L. Drabeck, I. B. Ferreira, K. Holczer et al., J. Appl. Phys. **70**, 496 (1991)] appears to be a very promising material for future applications. In collaboration with Dr. Chris Stevens (Oxford University, UK) the properties of Tl-2212 thin films with various doping concentrations are studied. As soon as samples are available we will investigate the to date unexplored c-axis response of the material as well as that in YBCO thin films. According to theoretical predictions, interlayer Josephson junctions can be formed in Tl-2212 and some preliminary reports show that Josephson plasma resonance could be observed in c-direction [V. K. Thorsmolle, R. D. Averitt, M. P. Maley, A. J. Taylor, and L. N. Bulaevskii (International Terahertz Workshop, Sandbjerg Castle, Denmark, 17-19 September 2000)].

Zusammenarbeit mit anderen Mitgliedern des Graduiertenkollegs

Dr. C.T. Rieck (theory of high temperature superconductors)
Dr. I. Wilke (THz spectroscopy of HTS, development of spectroscopic techniques)
Dr. Ines Meinel (clean room facility)
A. Jaye (maintenance of the ultrafast spectroscopy lab)
Prof. Dr. W. Hansen (Herstellung von LTGaAs für breitbandige THz-Emitter)

Ausblick

- Further development of the TDTS technique: change the detection part of the spectrometer in order to lift its upper frequency limit to 2.5 THz; finishing the building-up of the new convertible transmission-reflection time-domain THz spectrometer
- Study of resonance effects in YBCO thin films; a-axis oriented YBCO thin films
- Study of TBCCO thin films: influence of changing the doping level, possible observation of Josephson plasma resonance along c-axis.

Publikationen

Angehörige und Gäste des Graduiertenkollegs sind unterstrichen

[1] P. Kuzel, M.A. Khazan und J. Kroupa: *Spatio-temporal transformations of ultrashort THz pulses*, Journal of Optical Society of America B **16**, 1795 (1999).

[2] M.A. Khazan und I. Wilke: *Terahertz transmission of normal- and superconducting patterned structures*, Verhandl. DPG (VI) **35**, 786 (2000).

[3] I. Wilke, M.A. Khazan, C. T. Rieck, P. Kuzel, T. Kaiser, C. Jaeckel und H. Kurz: *Terahertz surface resistance of high temperature superconducting thin films*, Journal of Applied Physics **87**, 2984 (2000).

[4] I. Wilke, M.A. Khazan, C. T. Rieck, P. Kuzel, T. Kaiser, C. Jaeckel und H. Kurz: Time-domain terahertz spectroscopy as a diagnostic tool for the electrodynamic properties of high-temperature superconductors, 2000.

[5] M.A. Khazan, I. Wilke und C. Stevens: Surface impedance of Tl-Bi-Ca-Cu-O films at THz frequencies, submitted to IEEE Transactions on Applied Superconductivity 2000.

Teilnahme an Tagungen

- „Spatio-temporal transformations of terahertz pulses: a Gaussian description“
  M. Khazan, I. Wilke, P. Kuzel
  Annual Meeting of the Optical Society of America
  in Santa Clara, California, USA, 27th Sept - 1st Oct, 1999
  Beitragsform: Vortrag

- „Time-domain terahertz transmission spectroscopy and its application to the study of high-temperature superconducting thin films“
  M. Khazan, I. Wilke, P. Kuzel
  7th International Student Seminar on High-Temperature Superconductors and Ferroelectrics at Microwave Frequencies
  in Birmingham, England, 3rd - 8th June 2000
  Beitragsform: Vortrag

- „Terahertz transmission of patterned metal- and superconductor structures“
  M. Khazan, I. Wilke
  DPG Frühjahrstagung
  in Regensburg, March 2000
  Beitragsform: Poster

- „Dielectric function of YBCO thin films at THz frequencies“
  M. Khazan, I. Wilke
  International Terahertz Workshop (ITW 2000)
  in Sandbjerg Castle, Denmark, 17-19 September 2000
  Beitragsform: Vortrag

Forschungsaufenthalte und eingeladene Vorträge

- Laboratory of ultrafast phenomena, Institute of Physics,
  Academy of Sciences of the Czech Republic,
  Einladung durch: Dr. P. Kuzel, Dr. J. Kroupa
  in Prague October 1998

- Electron laser laboratory, Stanford university,
  in California, USA, October 1999

- THz spectroscopy group at the University of California
  Einladung durch: Prof. J. Orenstein
  in Berkeley, California, USA, October 1999

- Microwave spectroscopy lab at the University of British Columbia
  Einladung durch: Prof. W. Hardy
  in Vancouver, Canada, October 1999

- Department of Engineering Science, Oxford University
  Einladung durch: Dr. C.J. Stevens
  in Oxford, England, June 2000

Tagungsbeiträge als Mitautor

- „Numerical calculation of the complex conductivity of superconducting thin films“
  I. Wilke, M. Khazan, P. Kuzel
  Annual Meeting of the Optical Society of America
  in Santa Clara, California, USA, 27th Sept - 1st Oct, 1999
  Beitragsform: Vortrag

- „Time-domain terahertz spectroscopy as a diagnostic tool for the electrodynamic properties of high-temperature superconductors.“
  I. Wilke, M. Khazan, C.T. Rieck, P. Kuzel, C. Jaekel, H. Kurz
  Intl Conf. on Materials and Mechanisms of Superconductivity and High-Temperature Superconductors VI
  in Houston, USA, Februar 2000
  Beitragsform: Vortrag

- „Optical properties of glasses and ceramics for THz technology“
  H. Selig, M. Khazan, I. Wilke
  Conf. on Laser and Electro-O -optics European International Quantum Electronics Conference (CLEO-IQEC 2000)
  in Nice, France, September 2000
  Beitragsform: Poster

- „Study of carrier dynamics in LT-GaAs by means of time-resolved emission terahertz spectroscopy“
  H. Nemec, P. Kuzel, M. Khazan, S. Schnüll, I. Wilke
  Conf. on Laser and Electro-O -optics European International Quantum Electronics Conference (CLEO-IQEC 2000)
  in Nice, France, September 2000
  Beitragsform: Poster

- „Surface impedance of TBCCO films at THz frequencies“
  I. Wilke, M. Khazan, C. Stevens
  Applied Superconductivity Conference (ASC)

in Virginia Beach, USA, September 2000
Beitragsform: Vortrag

Eigene Vorträge im Rahmen des Graduiertenkollegs

- „Time-resolved terahertz spectroscopy of thin films and nanostructures“
  Workshop des Graduirtenkollegs
  in Niederkleevez, May 1999

- „Time-domain terahertz transmission spectroscopy and its application to the study of high-temperature superconducting thin films“
  Ringvorlesung des GrK Physik nanostrukturierter Festkörper, 28 Juni 2000