Modern techniques of terahertz-subterahertz spectroscopy of solids

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Abstract—**Modern techniques of terahertz-subterahertz (THz-subTHz) spectroscopy of solids are reviewed. Principles are described of the newly developed methods based on backward-wave oscillators (BWOs) which expand possibilities of standard BWO-spectrometers towards measurements of conductors and superconductors. It is demonstrated that the developed techniques can also be used by infrared spectrometers with other radiation sources, like free electron lasers or synchrotrons.**

I. Introduction

One of the most powerful experimental techniques in solid state physics is optical spectroscopy. It includes the study of the temperature-frequency behavior of conductivity $\sigma(\nu,T)$ and dielectric permittivity $\varepsilon'(\nu,T)$. Due to experimental difficulties, reliable spectroscopic data on materials in the THz-subTHz domain is practically missing, and this stimulates development of corresponding methods. Among the most successful are the time-domain spectroscopy (TDS) and the microwave vector network analyzers (MVNA). Both allow direct determination of σ and ε' but still suffer from serious drawbacks, like low and resolution dependent dynamical range (TDS) or inability in automatic recording of *spectra* of needed quantities due to mechanically tuned elements or/and unavoidable standing waves in the measurement channel (MVNA). One can also mention improvements of known optical and IR-techniques - Fourier spectroscopy and ellipsometry - oriented at mastering the lowest possible frequencies. These techniques, however, either do not provide direct (without Kramers-Kronig analysis) evaluation of the optical spectra (Fourier spectroscopy) or do not ensure measurements below several THz (ellipsometry).

In respect of providing the experimental THz-subTHz-*spectra* of solids still beyond the competition is the quasioptical spectroscopy based on BWOs [1].

II. Results

We analyze new BWO-techniques which significantly improve potentials of the standard BWO-spectrometers [1] and allow for direct measurements of the THz-subTHz (0.03 THz – 1.45 THz) spectra of $\sigma(\nu,T)$ and $\varepsilon'(\nu,T)$ of traditionally complicated for optical spectroscopy objects - conductors and superconductors. The techniques are based on determination of complex transmission coefficient of thin film samples on substrates and of reflection coefficient of an etalon dielectric plate put in contact with the bulk sample. In the first case, the complex transmission coefficient of a 2-layered system is measured and the parameters of the film are determined according to regular procedure [1]. In the second case, the interferometric minima in the reflectivity R spectra of an etalon plate are recorded and the shifts (in frequency $\Delta\nu$ and in amplitude ΔR) are determined caused by a sample put in contact with the plate's rare plane. We analyze potentials and accuracies of the new methods using graphs like the one given in Fig.1. We demonstrate that the developed methods allow measurements of materials with σ of up to 10^5 $Ohm^{-1}cm^{-1}$ and with negative ε' of down to -10^7, with accuracies ±(10 – 30)%.

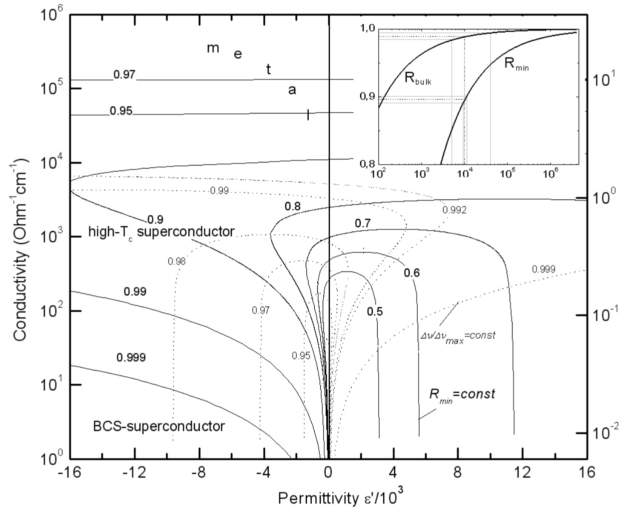

Fig.1. Illustration of dielectric measurements of a sample put in contact with an etalon dielectric plane-parallel plate (thickness d=1 mm and refractive index n=3) [1]. Lines - constant amplitudes and frequency locations of an interferometric reflection minimum in units $\Delta\nu/\Delta\nu_{max}$, where $\Delta\nu_{max}$ is the maximal shift corresponding to the "sample" with $\sigma=\infty$. Areas corresponding to various types of materials are indicated. Inset: dependence on the conductivity of the reflection coefficient of a bulk sample (a) and of the amplitude of an interferometric minimum (b). Grey lines: accuracies of determination of σ of the sample with $\sigma=10^4$ $Ohm^{-1}cm^{-1}$ if the accuracy of determination of the absolute reflectivity is 0.5%. In case (a) the uncertainty is of an order of magnitude, from $5*10^3$ $Ohm^{-1}cm^{-1}$ to $4*10^4$ $Ohm^{-1}cm^{-1}$ while in case (b) it is only ±10%.

References

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