Report on the doctoral thesis of Dr. Vít Zajac

Thesis title: Ultrafast response of electrons in nanostructured and disordered semiconductor systems studied by time-resolved terahertz spectroscopy

The thesis presents a suvey of both the experimental and theoretical achievements of Dr. Vít Zajac in the field of terahertz spectroscopy of semiconductor materials and semiconductor nanostructured systems. The topic is actual and fits into the contemporary research of the electron dynamics in nanostructures with a potentially high applicability in electronic devices.

The author gives an overview of the theoretical and experimental methods in the former introductory part and afterwards he presents his original contributions. The structure of the thesis and its division the chapters is clear even though I consider several subsections and further subdivision to the fourth level to be useless in this type of document since it does not improve the comprehesibility (for example section 2.3 has only one numbered subsection with two paragraphs and one figure). The graphical layout, to my opinion, is not clear and is confusing for readers. In particular the text footnotes should appear together with the figure caption footnotes at the very bottom of the page, usually separated by a horizontal line. In that case, it is useless to provide the chapter name on the bottom of the page. Figures and tables then should be placed on the top or bottom of the page and separated by a wider gap from the text so that one can clearly distinguish them (not like on p. 66 of the thesis).

When reading the introductory part of the thesis, I did not find a clear statement which part of the text is the introduction to the research subject and physical methods for readers and where the presentation of the author's original results begins. Therefore a confusion may arise concerning the chapters 4 and 5 which are dedicated to the effective medium theory. The reader would assume they belong to the overview of the theoretical methods used later in the thesis if there was not mentioned the author's contribution at the beginning of chapter 4. Despite this statement, it is not indeed clear which particular part is the author's original contribution. It is not also clear whether the data presented in fig. 3.1 on page 21 are an original result (therefore I would recommend a short comment on that fact) or not. In that case, a reference should have been given.

The first half of the thesis, where the basic concepts are overviewed, may be regarded as a compact and comprehensible introduction for the general audience to the relevant piece of the terahertz spectroscopy. There are just few places which would need an improvement, in particular the presentation of the time domain spectroscopy in section 2.2 is too short compared to the rest, although it is the main experimental technique in the work. Also a derivation or some comment on how one obtains the Maxwell-Garnett formula for the effective medium (3.15) on p. 26 would be instructive and I miss a precise definition of a very imporant parameter $\Delta\varepsilon$ on p. 41. Despite these minor remarks, this first half of the thesis is very well written and it clearly demonstartes the author's insight into the field and his ability to present it.

The overview of the results in the second part of the thesis is divided into the four chapters, according to the type of samples plus one chapter about numerical modelling of percolated systems. Each of the chapetrs itself represents a complex study of one distinct system with a proper presentation of the samples, measured data, data processing procedure, theoretical modelling and discussion with clear and well-founded conclusions. I would like to underline the presented theory in chapter 8 and the discussion of the results which serve together an excellent fit to the experimental data. In particular the chapter 8 demonstrates the ability of the author to find the microscopic physical processes, virtually responsible for the system's behavior, and to develop a relevant physical model which is able to reproduce the experimental data. This would not be possible without deep understanding of the underlying physics.

I propose the following questions for the discussion:

1. The wave equation for the transient terahertz field is discussed in chapter 2.3 and is introduced in the form of equation (2.3) with the source term (2.4) which appear together in equation (5.1). It is then stated below (5.1) that the transient field is much weaker than the probe field and therefore may be neglected on the right hand side in order to linearize the wave equation. To my opinion, the equation (5.1) is linear and such neglection is useless. Second, by neglecting the transient permittivity for the transient field, one introduces an artificial phase mismatch between the source and the induced field, leading to a wrong description of the system in thick samples. How may be this fact related to the interferences observed in chapter 6?

2. Could the author provide the figure 6.8 with the experimental curve? It is hard to compare the theory and experiment and to follow the discussion of the various interference effects. It is also not clear to me how the dephasing may cause the interferences. Please discuss this point in more details.

3. It is not also clear to me how one can renormalize the quantum yield parameter in discussion at the end of section 7.1. To my opinion, localized carriers do not contribute to the induced currents even though they contribute to the absorption. As a result, the mobility artificially rescales when setting $\xi=1$. Is the absorption coefficient of nanostructured silicon equal to the bulk value or there is a possibility that it is increased as much that one may consider that almost all of the absorbed photons are converted to the conducting electrons in the volume of the nanocrystals?

4. The effective mass of carriers in the theoretical simulations in chapter 8 is treated as isotropic even though one would expect a strong anisotropy due to the symmetry of the crystal lattice. In the particular experimental setup, effective mass along the main crystal axis defines the diffusion coefficient and the second effective mass then defines the magnitude of the mobility. Would the introduction of the anisotropic masses resolve the problem, which seems serious to me, that one of the scattering times change its value by one order of magnitude while the other one by two orders of magnitude when changing the temperature from 10 K to 70 K?

In summary, the thesis serves a compact and comprehesive overview of a valuable amount of the original results. Despite the above remarks, the presentation is clear and demonstrates the author's ability to work independently to achieve data, to interpret them as well as to present and discuss the results. Therefore I recommend the thesis to be accepted as the doctoral thesis after proper answering the above questions by the author.

In Prague, March 14, 2017

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