Prof. dr hab. Jacek Baranowski

Institute of Technology of Electronic Materials

Wólczyńska 133, 01-919 Warsaw

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Review of

Ewa Zbydniewska Ph.D. thesis

The Ph.D. thesis of M.Sc.Eng. Ewa Zbydniewska entitled "Electronic Properties of Coupled Semiconductor Nanocrystals and Carbon Nanotubes" is the result of the joint doctorate according to co-tutelle agreement between Faculty of Physics Warsaw University of Technology and Universite des Sciences et Technologies de Lille.

The research connected with this thesis was performed at this two universities. The Ph.D thesis has been published by Faculty of Physics Warsaw University of Technology in a form of 90 pages printed book.

The Ph.D thesis contains four chapters. The first chapter is devoted to a short description of fundamental properties of carbon nanotubes and their synthesis and dispersion. The second part of this chapter is devoted to description of carbon nanotubes transistors and their ability to switch between on and off states.

The second chapter of the thesis contains description of properties of semiconductors nanocrystals. In particular, attention is focused on description of optical blinking of quantum dots. In addition, the phenomena of random telegraph signal observed in electrical quantum dots is also described. At the end of this chapter the electronic properties of coupled quantum dots and carbon nanotubes are described. It is pointed out that 1/f noise is understood as the superposition of carrier trapped and de-trapped from defects states of nanocrystals situated in the transistor channel. Results from a few publications showing coupling of gold and CdSe nanocrystals with carbon nanotubes are presented. The first two chapters, which cover about 40 pages are describing the state of art of this field. They are based entirely on experimental results published by other authors.

Chapter 3 is devoted to experimental details connected with all steps that end with fabrication of carbon nanotube transistors decorated with semiconductor nanocrystals. For

preparation of carbon nanotube transistors the p-type of silicon substrate with thermally grown silicon oxides have been used. Carbon nanotube transistors have been fabricated using electron – beam lithography. All steps required for fabrication of carbon nanotube field effect transistors such as marker fabrication, carbon nanotube growth and deposition, carbon nanotube localization with respect to markers and finally contact formation are clearly described. Two types of carbon nanotubes were used for transistor fabrication. The first one is with nanotubes obtained from organic solution and the second one by Chemical Vapor Deposition growth directly on SiO_2 substrates. After the carbon nanotube growth, their deposition and localization which has been done using Atomic Force Microscopy. The next step was connected with fabrication of metal contacts to carbon nanotubes. After formation of contacts, the electrical characterization of carbon nanotube field effect transistors have been done. This step allowed to separate metallic nanotubes from semiconductor ones. The final step, which was indeed a challenging task was to place semiconductor nanocrystal in vicinity or directly on the carbon nanotube field effect transistor. This chapter contains also very important fluorescence results of CdSe nanocrystals capped with ZnS deposited on substrate covered by nanotube "carpet". The observation of fluorescents blinking of those quantum dots proved that there are sufficiently good for the most important result of this Ph.D. thesis the electrical blinking.

Chapter 4 contains the most important results of the Ph.D. thesis. This chapter is devoted to investigation of charge blinking and analysis of statistics of semiconductor nanocrystals revealed by carbon nanotube current. Electrical blinking manifest as a pronounced random telegraph signal associated with upper and lower current levels flowing through the carbon nanotube field effect transistor. Devices consisted of a carbon nanotube field effect transistor constructed from nanotubes grown by chemical vapour deposition and devices constructed from commercial nanotubes gave a similar results. It has been shown that nanocrystals produced random telegraph noise in the carbon nanotube field effect transistor current, where higher and lower current levels corresponds to change of nonocrystal charge by 1. This behavior was observed in both kinds of devices. Statistical analysis of both kinds of devices have shown that the random telegraph signal associated with electrical blinking exhibit characteristics of optical blinking such as power-law temporal statistic and a Lorentzian current noise power spectrum. It is important that power – law behavior observed in flow of the current, was consistent with the optical blinking observed from fluorescence

experiments. This was the first demonstration of electrostatic experiments, in which a power law statistical distribution of the nanocrystal charge state was observed. This was probably the reason for acceptation of her paper in Nano Letters.

The chapter 4 ends with analysis of physical mechanism associated with the nanocrystal electrostatic blinking. Her analysis lead to model of a two level random telegraph signal is associated with change of the population of nanocrystal traps with charging energy close to 200meV.

The experimental results and interpretation presented in the Ph.D. thesis are indeed on very high level. I have only one critical remark. There is lack of results of Raman experiments which are classical in identification of carbon nanotubes. In my opinion such results should be included in the Ph.D. thesis indicating that candidate is aware of this characterization technique. In addition, reading thesis and comparing its content with publication in Nano Letters one can notice that all results presented in the publication are included in the thesis. The Nano Letters publication has 7 other coauthors. Question arises, what are contributions of these other authors. In the acknowledgments the names of those authors are mentioned, however these names are not mentioned any more in the text of thesis. In spite of this remarks, I have no doubts that M.Sc. Ewa Zbydniewska as the first author of this publication play a leading role, and therefore, she actively participated in all experiments presented in the thesis.

My opinion of the thesis is very positive, and I propose to admit her to next steps of the procedure and finally to public defence of her thesis.