UNIVERSITÀ DEGLI STUDI DI SALERNO

Dipartimento di Fisica "E. R. Caianiello"

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Summary of the Ph.D. Thesis in Physics

Nanostructured materials for a new generation of electronic devices

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Summary

The thesis "*Nanostructured materials for a new generation of electronic devices*" by Alessandro Grillo aims to highlight the main results achieved during the candidate's PhD project on nanostructured materials for electronic applications. In particular, the main purpose of such project was to investigate how new classes of one- and two-dimensional materials could be exploited to realize different types of devices, such as field effect transistors and field emitters.

The thesis is divided into three chapters which deal with the following topics:

- Chapter 1 contains a brief account of the state of the art of modern MOSFET technology followed by an overview of the new possibilities introduced by the discovery of two-dimensional materials. Specifically, in the first paragraphs the operating principles of traditional field effect transistors are reported paying particular attention to their voltage-current characteristic, figures of merit and practical applications. In the next paragraph, the main non-ideal effects deriving from an excessive reduction in the size of the devices, necessary to improve their performance, are reported. Finally, the last two paragraphs delas with the discovery of graphene and other layered materials and their possible use as transistors' channel to avoid short-channel effects. The working principles of graphene-based transistors and their intrinsic limits, mainly due to the absence of bandgap, are reported. The last section discusses the properties of other classes of two-dimensional materials, such as transition metal dichalcogenides, compounds of the IV and V groups, black phosphorus and insulating layered materials that thanks to their astonishing mechanical and electrical properties could play a fundamental role in future electronic applications.
- Chapter 2 reports the original results obtained by the candidate from the study of three different two-dimensional materials (tungsten diselenide, black phosphorus and germanium arsenide) used as field-effect transistors channel. Specifically, in the first paragraph, the electrical properties of platinum diselenide, a member of the transition metal dichalcogenides family, are investigated.

Studying the electrical response of the material when exposed to supercontinuum withe laser irradiation, it has been demonstrated that the external pressure is responsible for different response to light, leading to positive or negative photoconductivity in vacuum and at a room pressure, respectively.

In the second paragraph, the results regarding a study on black phosphorus field effect transistors are presented. The aim of the research was to realize non-volatile memories exploiting the presence of intrinsic and black phosphorus/silicon dioxide interface defects achieving devices with good endurance and retention properties. Poly (methyl methacrylate) (PMMA) was used as covering layer to prevents the channel degradation, typical of black phosphorus devices, without affecting the electrical properties.

Then, in the third paragraph, a study on the electrical properties of germanium arsenide field effect transistors as function of temperature is reported. The devices were measured over a wide temperature range revealing that the carrier density presents a broad peak around 75 K. Such an anomaly was explained through a temperature-dependent conductive channel thickness model that was corroborated by the observation of three-dimensional variable range hopping conduction at lower temperatures that becomes band-type at higher temperatures.

Finally, the fourth paragraph presents a discussion about the analysis of current-voltage measurements of two-dimensional materials affected by the presence of Schottky barriers at both contacts. A model to analyse the transport mechanisms of these kind devices is proposed and tested on several current-voltage curves from different nanostructures, revealing a perfect agreement between the theoretical predictions and the experimental data.

- Chapter 3 reports others original results, achieved during the PhD project, about the field emission properties of nanostructured materials, such as nanotubes and nanopillars. The response to external stimuli, such as electrical and mechanical stress, has been investigated and new intrinsic properties of these nanostructured devices have been reported.

Specifically, in the first paragraph, an experimental study on the field emission properties of an individual gallium oxide nanopillar is reported. This material was selected because of its excellent physical and chemical properties, which combined with its ultrawide bandgap make it promising for conducting high current densities without damage. As expected, the experimental results demonstrated that gallium oxide shaped in the form of nanopillars can be a performant and competitive field emitter with low turn-on field and very high current density.

Finally, in the second paragraph, an experimental study on the electrical properties of multiwalled tungsten disulphide nanotubes under electron beam irradiation and axial strain is reported. The obtained good figures of merit suggest that tungsten disulphide nanotubes can be suitable for the realization of practical field emitting devices. Moreover, changes in resistivity for strain up to 12% evidenced another possible application as piezoresistive strain sensors.