THE CONCEPT OF OBTAINING SPINETRONIC NANOSTRUCTURES FOR QUANTUM DEVICES

Paata J. Kervalishvili

Georgian Technical University, Tbilisi, Georgia, paata.kervalishvili@gtu.ge

Abstract: The aim of the paper is elaboration of concept for obtaining spintronic nanostructures and quantum devices by Laser Plasma technology of 2D materials preparation.

Today when Moore law gradually loses its effect and conventional charge-based electronics will soon come to the end development of high speed and low energy consuming information systems is urgently needed. Up to now, many new methodologies have been proposed, such as molecular electronics, nanoelectronics, spintronics, magnetronics, optronics, etc. Modern Electronics (Micro Nano Spin Electronics) and its future mainly based on novel materials (metals and non metals), their preparation technologies and new properties. Perfection and ultra-purity are not the only parameters characterized materials usefulness for quantum devices. Modification of material properties by different structural nonperfections (structural defects: impurities, isotopes, etc.) is the smart instrument for regulation of their characteristics.

Based on difference from conventional electronics e electron’s which uses the electron’s charge degree of freedom for information processing, spintronics is devoted to incorporating the electron’s spin degree of freedom. Despite its great potential advantages, spintronics now faces a number of challenges, such as generation of fully spin-polarized carriers (pure spins) and injection of spin into devices, long distance spin transport, and manipulation and detection of carriers’ spin orientation. The solutions to these issues rely on the development of device fabrication and designing new spintronics materials with specific properties. Pure spin generation and injection mainly depends on the degree of spin polarization in the used semiconductors or metals. Thanks to the discovery of carbon-based nanomaterials such as graphene and carbon nanotubes, the challenge of long-distance spin transport is likely to be solved in the near future. Because of their very weak spin–orbit coupling (SOC), carbon-based nanomaterials can have a long spin coherence length up to a few micrometers, thus are very good spin transportation materials. As with spin manipulation and detection, there are some methods based on the coupling effects between spin and light, magnetic field, electric field, according to their electronic and magnetic properties, spintronics materials can be classified as magnetic metals, topological insulators, and magnetic semiconductors In a spintronic device, magnetic metals and topological insulators, serve as spin sources and drains, while magnetic semiconductors constitute the central region of the device.

At the same time usage of electron spins as quantum bits for quantum information processing in so called quantum computers is clear. Qubits in this state display a degree of correlations impossible in classical physics. This phenomenon is called entanglement and is crucial property of quantum computing. The main requirements of quantum computation are: Scalable physical systems with well characterized qubits (Zeeman Spliting); Long decoherence time: Existence of qubits at the ground state; Set of quantum gates; measurement capabilities, etc. Candidate for a qubit needs longer decoherence time than gate operation time. The transformation of digital computers from bulky machines to portable systems has been enabled by new materials and advanced processing technologies that allow ultrahigh integration of solid- state electronic switching devices. As this conventional scaling pathway has approached atomic- scale dimensions, the constituent nanomaterials increasingly possess properties that are dominated by quantum physics.

The convergence between quantum materials properties and prototype quantum devices is especially apparent in the field of 2D materials, which offer a broad range of materials properties, high flexibility in fabrication pathways and the ability to form artificial states of quantum matter. Along with the quantum properties and potential of 2D materials as solid- state platforms for quantum- dot qubits, single- photon emitters, superconducting qubits and topological quantum computing elements it is necessary to select the best method of their preparation.

Potential of laser plasma process for 2D materials preparation, particularly its usefulness for organization of nanostructures applicable in spintronic and quantum computing devices novadays is actively developing. Laser plasma formed under the ionizing effect of powerful laser radiation on the thing. For example, LP arises during optical breakdown in gaseous media, laser radiation on top solid body, in laser thermonuclear targets.

LP can exist in a wide range of temperatures - from 1 eV to 104 eV (104–108 K) and arising as a result of ionization of the electron impact with the subsequent image electronic avalanche, or as a result of many photons ionization. In LP. experimentally, self-focusing of the laser beam is observed. The impact of a light wave on LP leads to the formation of plasma waves (coil -ny electronic and ionic densities), which interact with the primary and scattered light then you wave. As a result, electric magnetic waves are formed with a frequency that is a multiple of the frequency of the incident light this wave (the so-called harmonics). The probability of generating high harmonics increases with an increase in intensity of laser radiation.

For preparation of 2D materials (semimetals, semiconductors) for novel quantum devices on the basis of our previous investigations we will develop and use the Laser-Plasma method which enables preparation of nanostructured layers with fine and perfect structures and high purity The properties of nanomaterials prepared by laser plasma technique are unique, and they are not reproducible by any other method including chemical ones. The usage of resonance light heat creates the opportunity to energize the selected atoms as well as their groups (assemble) and to produce plasma with the necessary properties relevant to structures which must be prepared. This technique was successfully used by the authors of the project to study the conditions for obtaining diamond-like films, as well as thin layers of boron carbide. See Fig.1.

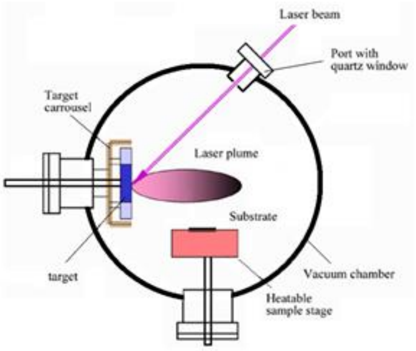

Fig.1. The scheme of experimental laser-plasma technology setup

In the last two decades, the Laser plasma method was used to form both homogeneously doped GaAs:Mn layers and two-dimensional structures, including a δ-doped GaAs:Mn layer and a InxGa1 – xAs quantum well separated by a GaAs spacer with a thickness of d = 3–6 nm. It is obvious that only Mn ions, which are part of the GaMnAs solid solution and are distributed almost uniformly in it, can noticeably exchange with quantum well carriers, leading to their spin polarization and, consequently, to the anomalous Hall effect.

We are looking for farther development of LP processes aim of preparation the next (higher) level of spintronic nanostructures based on above mentioned and some other diluted semiconductors.

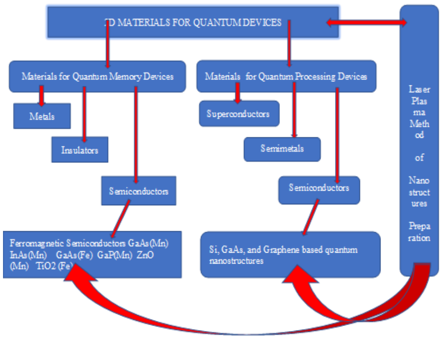

Fig.2 Roadmap of works related to obtaining spinelectronic nanostructures for quantum devices

Our works shown that the LP method and technology is very useful for preparation of semiconductor silicon and graphene nanosystem in one sandwich for creation of a new highly effective multiqubit element. (Fig.2). Graphene’s multilayers are forming stack – cluster with sublattices, which is a most common arrangement of nearest neighbour layers observed in nature. Selection of laser sources and their parameters is giving the possibility to vary the energy of ionized atoms in plasma plum, activate them to the necessary level and deposit the hot atoms and their clusters on substrates of different origin (semiconductors: Silicon, GaAs, etc.; Metals: Fe, Ni, etc.; Insulators: Al_2O_3, etc). For organization of these processes it is also possible to use the resonance wavelength of the light sources in order to have the direct and strong interaction with electron’s bonding energies.

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