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Alternative Technology for Creating Nanostructures Using Dip Pen Nanolithography[1]

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Abstract—For modern microelectronics, at the present time, the technologies of consciousness smart structures play an important role, which can provide accuracy, stability and high quality of the structures. Submicron lithography methods are quite expensive and have natural size limitations, not allowing the production of structures with an extremely small lateral limitation. Therefore, an intensive search was conducted for alternative methods for creating submicron resolution structures. Especially attractive one is the possibility of self-organization effects utilization, where the nanostructure of a certain size is formed under the influence of internal forces. The dip pen nanolithography method based on a scanning probe microscope uses a direct-write technology and allows one to carry out a playback of small size structures with high accuracy. In the experiment, a substrate coated with Au (15 nm) using a DPN technique is applied to the polymer to form a desired pattern nano-sized channel. The experiment was conducted using a pointed probe SiN, coated MHA-Acetonitrile, on the Si(111)/Fe_3Si/Au structure.

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1. INTRODUCTION

Low-dimensional structures are currently used in many fields. In medicine, low-dimensional structures find new applications ever. [1, 2]. Moreover, the prospects for their use in electronics are practically limitless. In spintronics—a multi-disciplinary field of science and technology, the central theme of which is the phenomenon of spin-dependent electron transport in solids and low-dimensional structures special attention is paid to the quality of structures. Spintronics covers the most interesting and fundamental questions of spin-dependent phenomena and practical issues related to the creation of new electronic devices based on the ability to manipulate the spin degrees of freedom [3, 4]. However, despite the prospect and relevance in the field of semiconductor, spintronics only at the very beginning of its development. Major research efforts are directed to search for materials and methods of the construction of hybrid structures, the choice of topology, to find new manifestations of spin-dependent electron transport in hybrid structures, searching for new ways to manipulate the spin state of charge carriers in semiconductors and hybrid structures. Spin-electronics devices are more demanding of the size, the boundaries of quality and physical properties of materials, compared to the classical microelectronics devices. This leads to the fact that classical microelectronics device manufacturing technology is not always possible to obtain the desired results. An alternative technology for the manufacture nanoscale structures is the method for forming structures using a Dip Pen Nanolithography (DPN) [5].

The DPN has recently been proven to be a useful tool for the direct writing of diverse nano-patterns on a substrate. A dip-pen nanolithography based strategy for fabricating and functionalizing Au nanostructures on a semiconductor substrate. Method DPN uses as a writing element probe atomic force microscope coated with "ink". By changing the surface character by movement of the probe, such as its speed or delay time can create a variety of different types of patterns. This method allows one to work in the sub-50 nm resolution with precise control over the size and the distance between the elements [6]. It uses a method that combines high-resolution pen nanolithography techniques with chemical etching to create structures with Au-coated.

[1] The article is published in the original.

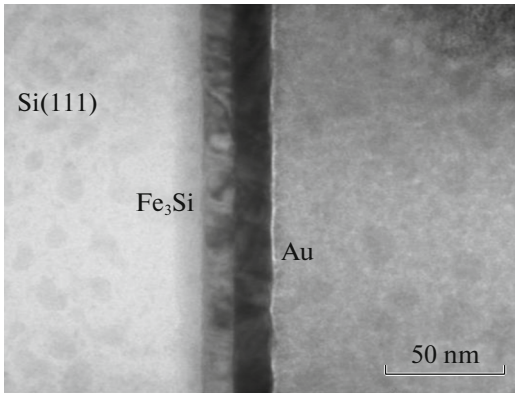

Fig. 1. Cross-sectional TEM image of Si(111)/Fe_3Si/Au. The thickness of the silicide layer is 13 nm, and the gold layer is 15 nm.

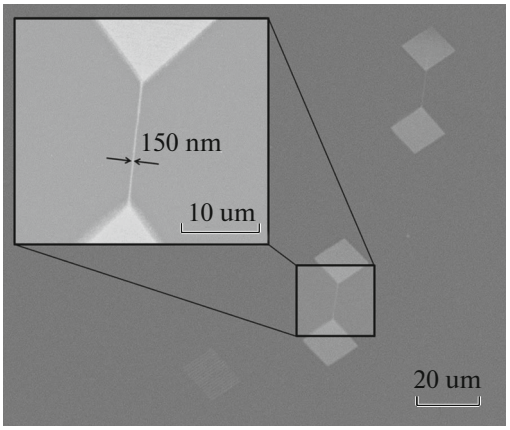

Fig. 2. SEM images of a nano-sized channel of Fe_3Si/Au on Si(111).

2. EXPERIMENTAL

This paper describes the process of manufacturing the structure with the nano-sized channel. Scanning probe microscopy can be used not only for analysis and surface characteristics but also to modify it. We used the DPN 5000™ system, which is a powerful and easy-to-use tool employing a modified atomic force microscope and proprietary NanoInk software to create nanoscale patterns on material surfaces. The basis for the structure is heterostructure Si(111)/Fe_3Si/Au (Fig. 1) obtained by thermal evaporation in a high vacuum at a molecular beam epitaxy "Angara" [7]. The growth rate and the thickness of Fe and Si layer were monitored by in-situ high-speed laser ellipsometer LEF-751M.

In DPN, the tip of an atomic force microscope probe is coated with ink and traced across a target surface. As the probe traverses the surface, the ink is deposited along the tracing path and diffuses away from the tip through the water meniscus. By varying the tip speed and/or dwell time, it is possible to create lines of various widths and/or dots of various radii, and the lines and dots can be combined to create complex patterns. The instrument uses an environmental chamber capable of controlling temperature and relative humidity through a real-time feedback loop. Environmental conditions were kept constant throughout all experiments. The NanoInk Chamber software permits environmental stabilization while being able to avoid associated noise by turning off the heater and nebulizer during writing and imaging. DPN can operate under different environmental conditions, keeping the tip and structure the same. While exploring minimum line width dependencies on surface roughness and tip radius, we kept environmental conditions stable at $T = 27 \pm 0.1$°C and RH = 38 ± 0.5%. This way we formed the nanoscale channel on the Si(111)/Fe_3Si/Au structure using the SiN probe coated with MHA-Acetonitrile.

After DPN procedure the structure patterned with the polymer (MHA-Acetonitrile) was further created by a chemical etching process. Firstly, to remove completely Au from areas, which are not covered with MHA-polymer, the structure was treated for 18 minutes in the wet etching of 1:1:1:1 (v/v/v/v) aqueous mixture of 0.1M $Na_2S_2O_3$, 1.0M KOH, 0.01M $K_3Fe(CN)_6$ and 0.001M $K_4Fe(CN)_6$ [8] with constant stirring. Wet chemical etching with constant agitation and temperature of 22°C in a liquid mixture of hydrofluoric acid and nitric acid ($HF:HNO_3:H_2O$ = 1:2:400 at 22°C) [9] were utilized to remove a layer of silicide. In the end, we obtained a nano-sized channel 150 nm wide (Fig. 2).

3. RESULTS

Shows a process by which a substrate coated with Au (15 nm) using a DPN technology is applied to the polymer to form a desired pattern nanochannel. After DPN operation, the structure patterned with the polymer (MHA-Acetonitrile) was processed with a two-step wet chemical etching process. As a result, we obtained a nano-sized channel 150 nm wide. The DPN technology can be used to generate the desired hybrid topology structures that will be used to study effects of the spin-dependent transport in various devices. Proven technology provides the device with the necessary topology control electric and magnetic electrodes for the implementation of the spin transistor.

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