INTRODUCTION

The development of new methods for creating quantum-dimensional systems based on silicon and its compounds is a challenging problem of modern semiconductor materials science. Owing to these systems, the difficulty of application of silicon as light-emitting semiconductor devices in photoelectronics, which is caused by a low radiative recombination probability induced by forbidden direct carrier transitions during recombination, was overcome. As a result, a new impulse of a wide application of silicon in opto- and microelectronics was formed. The development of methods for creating silicon spatial quantum-dimensional structures, such as photonic crystals and nanocomposite materials, is now of particular interest. The effect of a matrix, i.e., a medium for objects with size-dependent properties, is an important factor that determines the properties of nanomaterials. Such objects can be used to create nonlinear nanosystems for optical transducers and light-tunable diodes and lasers with a variable wavelength.

The morphology of the surface on which islands form is the factor that favors the ordering of 3D islands in size and spatial distribution during the formation of quantum-dimensional systems [1]. The nanomorphology parameters can be controlled by lithography, which makes it possible to create “windows” on a substrate to limit the region of accumulation of adatoms into an island and to separate islands from each other. However, the existing high-resolution lithography methods have disadvantages, which restrict the field of its application in experimental techniques. Therefore, the self-organization processes that occur during the formation of nanosized 3D island structures, which can be formed upon the deposition of submonolayer coatings on the atomically clean surfaces of semiconductor crystals, attract attention of researchers [2]. The development of this field in the technology of producing nanosystems, which is based on using the atomic structure of pure semiconductor crystal surfaces for the formation of equilibrium 3D arrays of nanosized islands of foreign materials with an ultra-high surface density and for its application as self-organized mask coatings for selective high-resolution plasma-chemical etching.

The purpose of this work is to study the kinetics of structuring submonolayer carbon coatings on (100) silicon in the microwave plasma of low-pressure ethanol vapors is studied by atomic force microscopy and scanning electron microscopy. The laws of influence of the substrate temperature and the kinetic energy of carbon-containing ions on the mechanisms of formation and structuring of the forming silicon—carbon surface phases are established. It is shown that the deposited carbon-containing nanodomains can be used as nonlithographic mask coatings for the formation of spatial low-dimensional systems on single-crystal silicon upon selective highly anisotropic plasma-chemical etching.

EXPERIMENTAL TECHNIQUE AND RESULTS

The experiments related to the formation of atomically clean silicon (100) surfaces, the deposition of submonolayer carbon island coatings, and highly anisotropic selective dry etching of silicon using deposited mask coatings were carried out in one vacuum technological cycle in a facility with a microwave
The surface nanomorphology on a silicon wafer was studied by a Solver-P-47 atomic force microscope (AFM) and an Auriga electron microscope. As an AFM probe, we used standard silicon CSG10 silicon pyramidal cantilevers with a radius of curvature of 10 nm and a stiffness of 0.1 N/m. The field of scanning was 3 × 3 μm at a scanning step of 8 nm and a DAC piezoelectric scanner step of 0.24 nm along axis y. The scheme of detecting the cantilever deviation ensured a resolution of 0.1 nm at an ADC piezoelectric scanner step of 0.05 nm along axis z. The measurement results were processed with the software of the microscope.

Figures 1–4 show the kinetic dependences of the nanomorphology parameters of the silicon (100) surface after the deposition of carbon in the microwave plasma of ethanol vapors at various substrate temperatures and bias voltages applied to the substrate holder. (The coordinates at t = 0 s in these figures correspond to the microasperity density and height on silicon wafers after their preliminary processing in the microwave plasma of argon.) It is seen from Fig. 1 that the dependence of the surface microasperity density on the deposition time at $U = -100$ V has two growth segments, which are separated by a region with the minimum density where the microasperities are at the level of the initial (without carbon deposition) microasperity density on the silicon surface. In this deposition time range (4–7 s), the microasperity heights are maximal. Then (at $t > 9$ s), they decrease rapidly and reach the constant values that were before deposition, and the microasperity density begins to increase according to a power law.

Figure 2 shows AFM images of the surface nanomorphology of the carbon coatings deposited onto (100) silicon in the microwave plasma of ethanol vapors at $T_s = 100^\circ$C, $U = -100$ V, and various deposition times.

In contrast to the deposition at $U = -100$ V, the microasperity density as a function of the carbon deposition time at $U = -200$ V has a smooth character and very weakly decrease rather than increasing at a very long deposition time. Another radical difference between the dependences at $U = -100$ and $-200$ V is the fact that the extremum of the microasperity height in the latter case is sharper, is higher by a factor of 2, and takes place at a shorter deposition time, 4–5 s (Fig. 1b). The shift of the deposition time at the extremum is about 2 s.

As the bias voltage increases to $-300$ V, a pronounced maximum, which is higher than those at lower $U$ by a factor of 2–4, appears in the dependence of the microasperity density. This maximum appears at a deposition time of 4–5 s, and the density then rapidly decreases to the value that is close to the microasperity density at $U = -200$ V. At all deposition times, the microasperity heights remain almost the same and close to the microasperity heights on the initial silicon wafer. This finding indicates almost uniform layer-by-layer deposition of a carbon coating at $U = -300$ V for all deposition times.