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Peculiarities of Morphology Formation of Silicon Surface under the Action of Laser Pulses

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The experimental studies of geometry features of silicon layers in areas of second and millisecond laser pulses were carried out. The results of microscopic studies of periodic structures that are formed on the surfaces with crystallographic orientation (111) (110) (100) and on planes, cut at an angle of 6° to the plane (100) and amorphous layers B_2O_3 deposited on the surface of silicon were presented. The results can be used to determine the crystallographic orientation of the semiconductor surface and express assessment of disorientation degree of crystal surface.

Keywords: electron-hole plasma, recrystalized area, periodic structures.

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Introduction

Modeling surfaces of crystalline solids and processes of their interaction with powerful laser pulses occupy an important place in modern materials science [1-3]. Present study opens great opportunities in both classical and quantum experimentally neglected processes of self-organization of terrain, structural and electronic effects on the surface of condensed systems. Acquisition of functional surficial nano- and microstructures open the possibility of new optical surface properties by particular excitation of surface plasmons suitable to generate plasmon components of electronic circuits, high light absorption, surface crystallography analysis, etc. Under the action of millisecond and second laser pulses on silicon semiconductors such photoinduced maximum concentration of nonequilibrium carriers does not exceed $10^{18}cm^{-3}$ and is significantly lower than the value obtained by excitation of semiconductors by nanosecond laser pulses ($5\cdot10^{19}cm^{-3}$). Relatively low concentration of electron-hole plasma (EHP) induced in the semiconductor laser pulses and second-millisecond range can be redistributed influenced by both external and its own intracrystalline fields. This bundle of electron-hole plasma leads to new physical phenomena caused by the instability of the parameters of semiconductors and self-organization in systems derived from thermodynamic equilibrium. [4, 5].

In this work the results of experimental studies of the physical processes that cause non-uniform melting of semiconductors and leads to the formation of surface periodic structures in the areas of laser pulse action are presented.

I. Experiment

Experimental studies were carried out on samples of dislocation-free silicon oriented in planes (111), (110) and (100). Along with samples prepared by the conventional method, in particular for the detection of dislocation pits digestion, research was also conducted on the plates obtained by cleavage of crystals in a vacuum in the mechanism VUP-5. Time of freshly cleaved surface presence in a vacuum of 10^{-4} Pa did not exceed 1 s. In addition, a thin (200 Å) amorphous film B_2O_3 was deposited on the surface of the crystals by vacuum to reduce thermal stresses that arise in the areas of laser radiation and leveling of the temperature field. Irradiation of the crystals was carried out evenly across the surface using two types of lasers: continuous CO_2 laser (λ = 10,6 mkm) power of 1 kW, the beam diameter of 3 cm and a pulsed neodymium laser type GOS-300 (λ = 1,06 mkm) that worked in free running mode (T_i=10^{-3} c, $q = 10^4 \div 10^5$W/cm^2). Measurement of geometric surface structures was executed by scanning profilometer Talysurf-5M. The study was conducted on a sample size of 1 cm x 1 cm. Diameter of the probe was 2 mkm. Stereometric 3D figures of the analyzed surface sample were created on a special software for the profilometer.

II. Results and discussions

Research topography of the areas that were formed due to crystallization of local smelting holes semiconductors showed the presence of characteristic surface contour of the land. After reaching the maximum melting due to the surface tension forces, liquid phase separation - the minimum air space - in the melting surface is formed. Nonequilibrium melt surface level appears to be lower than the initial level of the solid surface, because the melting point of silicon specific volume of fluid is less than the amount of solids: $V_{solid\ phase} = 12{,}1\ cm^3/mol$, $V_{liquid\ phase} = 10{,}9\ cm^3/mol$ (Fig. 1, a, b, c). Crystallization melting begins on the verge of separating liquid and solid phases, during which there is a change of surface area edges by increasing the volume of the silicon during recrystallization.

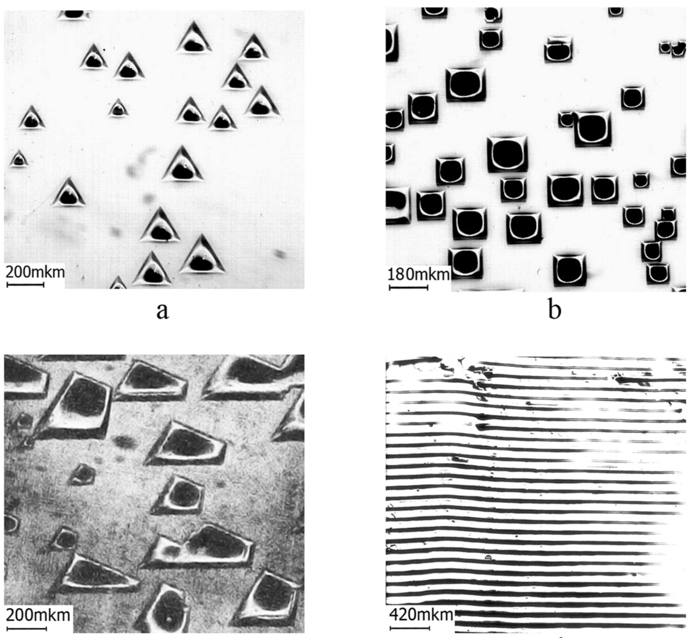

Fig. 1. Microphotographs of silicon surface in the area of the second pulse CO_2 laser: a - (111) Si, b - (100) Si, c - cut at an angle of 6^o to the plane (100) Si, d - a periodic structure on Si.

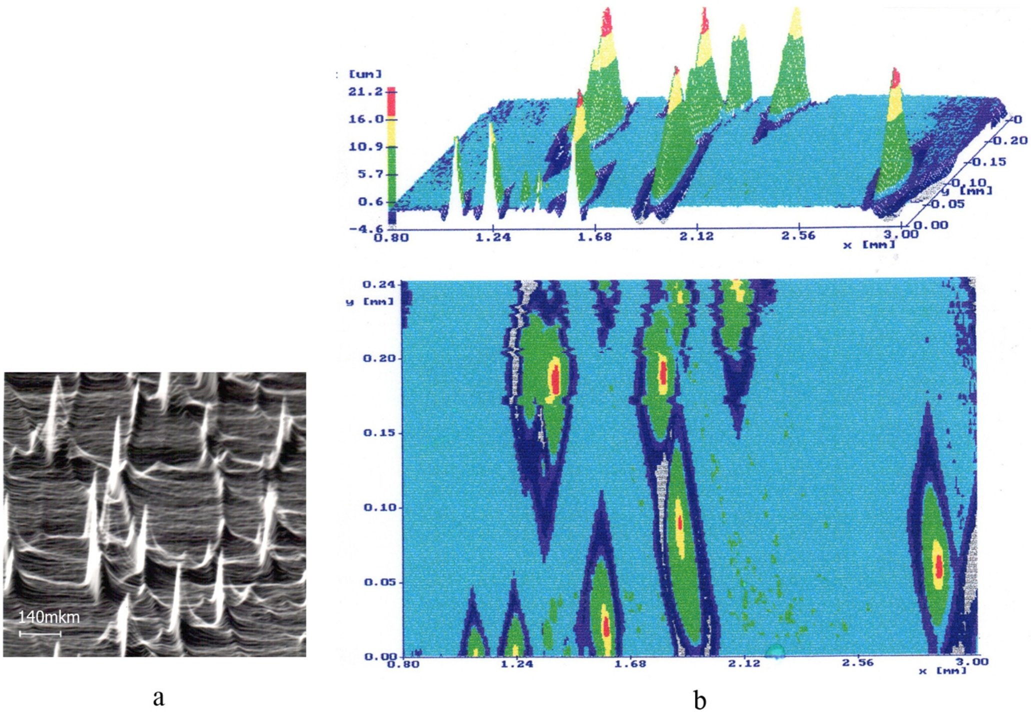

Fig. 2. Microphotography of local meltings of recrystalized silicon laser field (a) and a three-dimensional image of topographical map of the area (b).

Since the symmetry of introcrystallic field is determined by the symmetry of the crystal, then the uniform excitation of semiconductor laser radiation with subthreshold power (lower than the threshold at which the homogeneous melting of the surface layer occurs) on the irradiated surface locally melted areas are formed. They reflect the distribution of the concentration of nonequilibrium charge modulated by introcrystallic field. The form of local melting wells is associated with crystallographic orientation of semiconductor surface (Fig. 1). For example, on the plane (100) square holes of meltings are formed, on the plane (111) - triangular, and on the plane (110) melting wells have hexagonal shape. At certain energy parameters of light stream through the actions of intro-crystallic fields the formation of periodic surface structures is formed (Fig. 1, d). In addition to determining crystallographic orientation of the surfaces of semiconductor laser method also can be used to assess the degree of disorientation express the crystal surface.

Level of the surface near the boundary of the nonequilibrium melting is below the initial level of the crystal and has a protrusion in the center. Protrusion height is about 10% of the horizontal width of the field (Fig. 2). It is established that the morphology of the surface of the semiconductor in the areas of laser radiation depends on the initial temperature of T_0 samples. The surface relief becomes more shallow when T_0 increases, the average period between local melting holes decreases. The average period between different local melting areas at T_0 = 80K is 1,5 times higher than the corresponding average of the period at T_0 = 300K.

EHP mechanism of instability was caused by the dependence of the absorption coefficient of light flux on the concentration and temperature of the charge carriers, and thermal diffusion and dependence of flow of carriers on changes in the band gap (Fig. 3) [6]. During increasing fluctuation of carrier concentration in some part increases energy absorption capacity of luminous flux and therefore increases local heating of the semiconductor. At high temperatures, semiconductors in nonpolar carriers mainly scatter their pulse on deformational potential of acoustic and optical photons. Therefore, diffusivity decreases when the temperature increases, which means that the thermodiffusional flow carriers of charge is directed in the area of high temperature of crystal lattice. That leads to further increase of the degree of absorption capacity flux. If the band gap E_g is a decreasing function of temperature, the flow of charge carriers caused by local bend zones will be also directed to the region of increased temperature. Therefore, the temperature distribution during heating will be greatly uneven only when the leveling speed inhomogeneous temperature distribution is less than the rate of heating of the semiconductor. Thus, the mechanism of instability of the electron-hole plasma under the action of intense light beams on semiconductors is caused primarily due to thermal diffusion of electrons and holes and increasing temperature due to recombination in areas with high

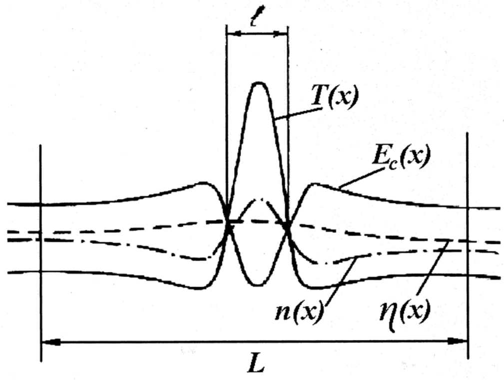

Fig. 3. Distribution of temperature T (x), energy level of the bottom of the conduction band Ec (x) and carrier concentration n (x) in the form of strut which are realized under quasi-stationary heating of the semiconductor.

concentration of charge carriers, or in other words, thermodiffusional instability of EHP is caused by pumping in a high temperature more carrier concentration, which, in turn, leads to an increase in the degree of absorption of light flux and hence cause temperature increase. Thus there is a positive reaction between the temperature of the crystal lattice and the concentration of charge carriers in their fluctuations, which leads not only to amplification of initial fluctuations in temperature, but also to the formation of a quasi-periodic semiconductor temperature fields of large amplitude. Inhomogeneous temperature fields define features of melting, crystallization and formation of topography of semiconductors in areas of laser radiation. In addition, quasi-neutral electron-hole plasma in semiconductors initiated by action og millisecond and second laser pulses can be a very sensitive indicator of effects on materials as external fields (temperature, deformation) and own intro-crystallic fields. Features of modulation distribution of photoinduced carriers by intro-crystallic field are easily detected by the morphology of the surface in areas of laser radiation.

Conclusion

Stratification of electron-hole plasma in semiconductors is initiated by the laser pulses of second and millisecond range, it can be effectively used to determine the crystallographic orientation of surface of the semiconductor, to quick assess of the disorientation degree of surface of the crystals and determine the structure of semiconductors in general.

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Особливості формування морфології поверхні кремнієвих пластин при дії лазерних імпульсів

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В роботі проведено експериментальні дослідження особливостей геометрії поверхні кремнієвих пластин в зонах дії секундних і мілісекундних лазерних імпульсів. Наведені результати мікроскопічних досліджень періодичних структур, які формуються на поверхнях з кристалографічною орієнтацією (111), (110), (100), а також на площинах, вирізаних під кутом 6^{o} до площини (100) і на аморфних шарах B_2O_3, нанесених на поверхню кремнію. Одержані результати можуть бути використані для визначення кристалографічної орієнтації поверхні напівпровідників та експресної оцінки ступеня розорієнтації поверхні кристалів.

Ключові слова: електронно-діркова плазма, рекристалізована область, періодичні структури.