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Study of van der waals surfaces along the layer of $TlInS_2$ and $TlInS_2$ <0.1%V> crystals irradiated with γ-quanta

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The aim of this study is to determine the fundamental physical regularities of nanoplastic deformation on the surfaces of layered $TlInS_2$ and 0.1% vanadium-doped $TlInS_2$ crystals irradiated with gamma rays and to study the general kinetic processes affecting their surface structure at the nanoscale. The geometric dimensions and profiles of structural formations in the Van der Waals surface layers of $TlInS_2$ and $TlInS_2$ <0.1%V> layered crystals irradiated with γ-quanta were determined by atomic force microscopy. The effect of radiation increases the saturation degree of nanoscale clusters, enhances the dissociation ability of molecules and leads to the formation of critical nuclei. The rapid formation and growth of a large number of nanoscale cluster nuclei occurs during the catalytic action of the metal. As a result of the radiation effect, the growth of conical clusters occurs.

Keywords: atom power microscopy, Van-der-Waals surface, histogram, profilogram, nanoscale.

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Introduction

From this point of view, it is interesting to study the formation of nano-sized cavities on the Van-der-Waals surface of the layered $TlInS_2$ crystal irradiated with γ-quanta [1]. It was found that linear defects and nano-sized voids of various shapes appear on the Van der Waals surface of the $TlInS_2$ crystal as a result of plastic deformation [2]. The self-organization of nanoobjects within the $TlInS_2$ crystal can lead to the integration of their interactions and the formation of new nanophases due to the superstoichiometric diffuse atoms and interlayer interactions [3].

In principle, by taking the $TlInS_2$ matrix, the formed nanoobjects can be controlled and suitable nanostructured fragments can be created. In this case, the characteristics of interlayer nanostructures are clarified through the study of surface morphology and additional atoms [4].

The S atoms forming the Van der Waals surface of the $TlInS_2$ crystal are non-metallic, which primarily accounts for the challenging oxidation of these layered crystals [5]. The high durability and minimal surface roughness enable the study of the chipping morphology of the $TlInS_2$ surface using atomic force microscopy in air and at room temperature [6].

When presenting the real structure of the studied surface, it is essential to consider the presence of a thin oxide layer on the Van der Waals surface of the layered crystal after a few minutes of exposure to air [7]. Probe microscopy, which includes atomic force microscopy (AFM) and tunneling-force microscopy (TFM), is the primary method for measuring nanometer-scale surfaces. [8].

The name of the method is determined by the physical forces used [9]. In AFM studies, the interaction between the probe tip and the surface in non-contact mode on oxidation surfaces is determined by the electrostatic charges on the oxide surface and the Van der Waals force [10]. These AFM studies were conducted in air after sample preparation [11].

The strength of the interatomic interaction in the studied crystals is characterized by three parameters [12]: the radius of motion, where the forces are negligible [13]; the bonding energy value; and the properties of the electron density and the spatial distribution of valence electrons [14].

I. Experimental Technique

The morphology of the Van der Waals surface of $TlInS_2$ and $TlInS_2$ doped with 0.1% vanadium atoms was studied using atomic force microscopy at room temperature [6].

The studies were conducted using Solver-NEXT AFM. The layered sample was placed on the scanning stage of AFM. It is known that the surfaces of layered crystals are atomically smooth and S atoms cover the surface, so it is possible to measure the $TlInS_2$ crystal without additional surface preparation, considering the low oxidation rate [9]. The scanned area, approximately 5x5 μm^2, was determined using a video camera with 100x magnification mounted on the microscope interface.

From the AFM images, the roughness rms value of a clean $TlInS_2$ substrate was found to be ~ 0.05 nm, indicating an atomically smooth surface [6]. Molecules adsorbed on the surface form nanoscale clusters arranged orderly [12]. Research interest in this field is related to obtaining various nanostructures up to 100 nm [7]. Layered semiconductors, under spontaneous arrangement of nanostructure additives, can produce derivatives on the Van der Waals surface and thereby create a localized potential for current carriers. These additions result in superlattices consisting of nanowires, nano-islands and quantum dots, forming the basis of optoelectronic and thermoelectric devices with periodic structures [15].

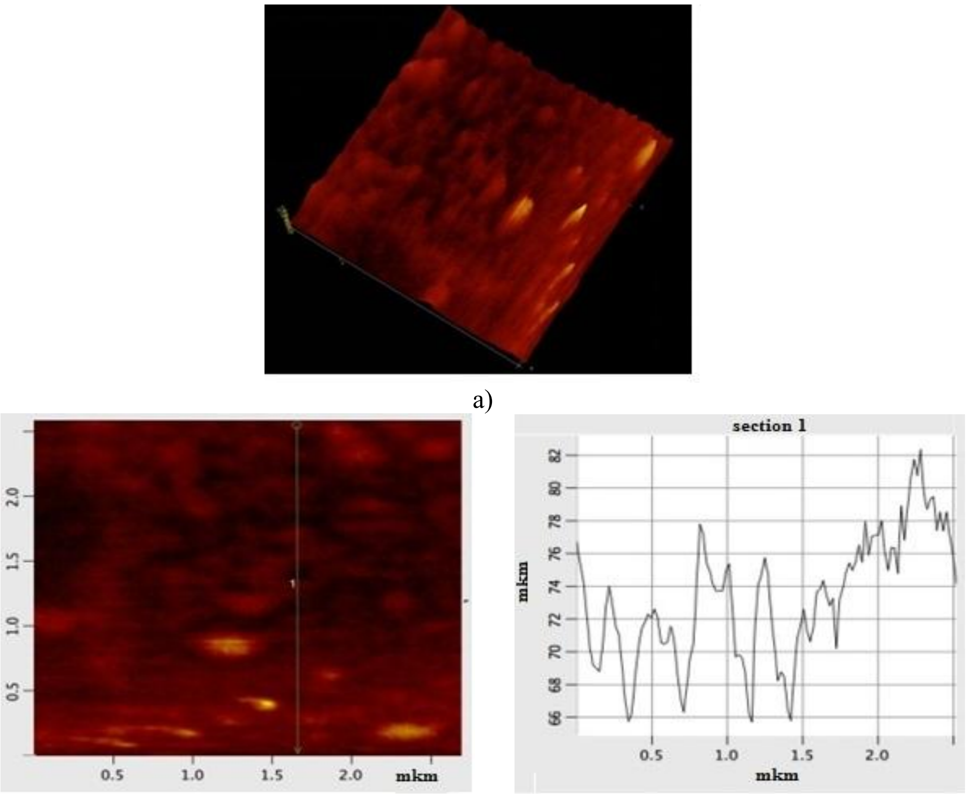
Surface defects are formed due to irregularity mechanism, leading to dislocations that easily break down into segmental dislocations. As a result of the elastic interaction of the dislocation systems located very close to each other in the basic areas of the anions, a nanoscale dislocation relief is formed on the Van der Waals surface [3]. The isotropic distribution of surface stresses exhibits monoclinic symmetry and is characterized by lateral dimensions up to 100 nm [4]. Defects on the van der Waals surface serve as a center for localized free bonds and act as active centers during atom insertion. [6].

Given the limited information about the surface properties of the studied samples, the scan was started from ~ 14 μm^2. Based on the scanning results, the optimal scanning rate was determined and selected. Considering the optimal rate and value, the scanning area was shifted to the smallest side. Based on the scanning results, further scanning parameters, such as the selection of the resonant frequency of the probe, which determines the sensitivity of the probe and the minimum distance between the measured surface and the probe. Also, a scanning rate of 4 μm/sec scanning step and feedback gain were set. [1].

II. Results and Discussion

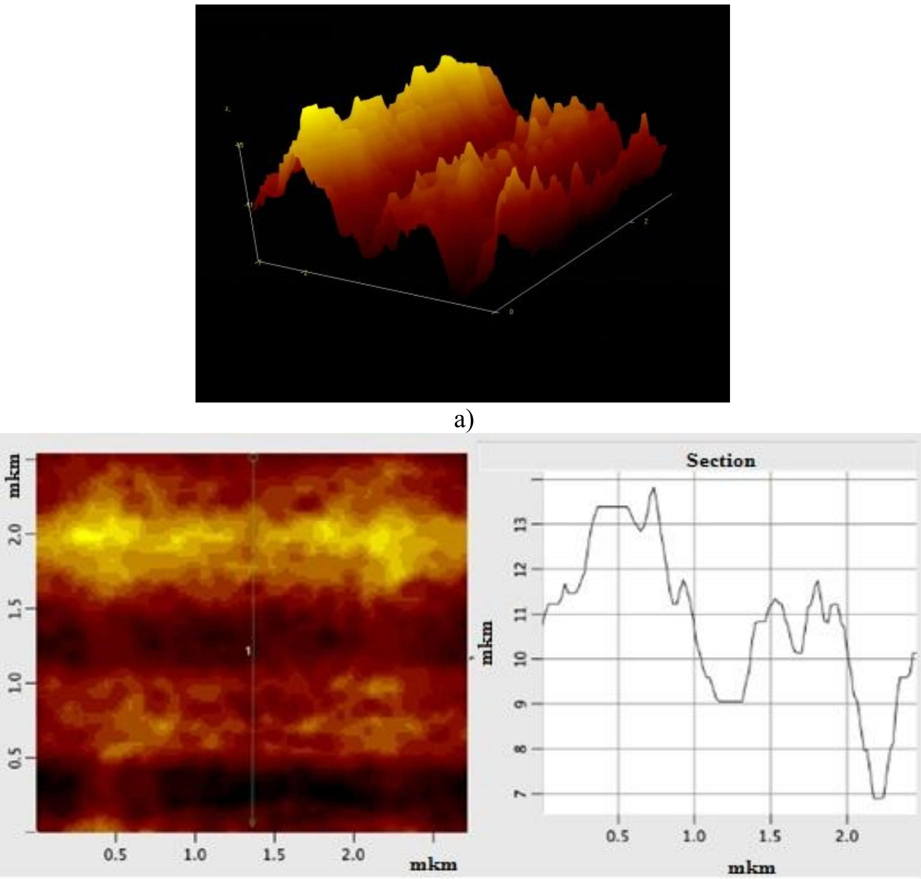
2D and 3D images of the surfaces of surfaces of gamma-irradiated $TlInS_2$ and $TlInS_2$ <0.1%V> crystals are shown in Figures 1 (a, b) and 2 (a, b). The 3D AFM images of $TlInS_2$ and $TlInS_2$ <0.1%V> crystals at room temperature revealed separate whisker nanomaterials, which took on conical shapes (Fig. 1 a and Fig. 2 a).

Figures 1 (b) and 2 (b) display the 2D image and profilogram of the surface within the AFM area 30x90 nm^2, drawn along the axis of the division direction, using the scanning method [6]. As depicted in Figures 1 b



b) c)

Fig. 1. Atomic force microscope image of the Van der Waals surface of a γ-ray irradiated $TlInS_2$ layered crystal:



a)

b) c)

Fig. 2. Description of Van der Waals surfaces of $TlInS_2$ <0.1%V> layered crystal with γ -quanta: a) in 3D format b) in 2D format c) selected profilogram fragments from 2D format. In image c, the line is shown longitudinally.

and 2 b, the profile height ranges between 4-7 nm and the lateral dimensions can reach 10 nm. Scanning the sections of the surface of $TlInS_2$<0.1% V> crystal on the order of tens of microns did not alter the structure or morphology of the surface. The occurrence of corrugated structures can be attributed to the directional transport of atoms along the surface, resulting in the formation of wavy and stepped structures in semiconductor crystals. The maximum height difference in the [001] direction of the selected surface is 40 nm and, as can be seen, the $TlInS_2$ surface has a corrugated shape where the self-organization processes occur [11].

Figures 1. c and 2. c illustrate that these self-organized, corrugated structures exhibit fractal profilograms with height differences of several nanometers [12].

The study investigated fundamental physical regularities of nanoplastic deformation on the surfaces of surfaces of gamma-irradiated layered $TlInS_2$ and $TlInS_2$ <0.1%V> crystals, as well as their general kinetic processes influencing the surface structuring at the nanoscale [8]. The research examined the regularity in the formation and alteration of the surface layer of corrugated and dislocated structures and the impact of the kinetics of surface structures at various stages [7].

As can be seen from Figure 3, polygonal nano-sized grooves layered with 0.1% vanadium atoms are observed in the upper layer of $TlInS_2$ and $TlInS_2$ crystals irradiated with γ-quanta [16].

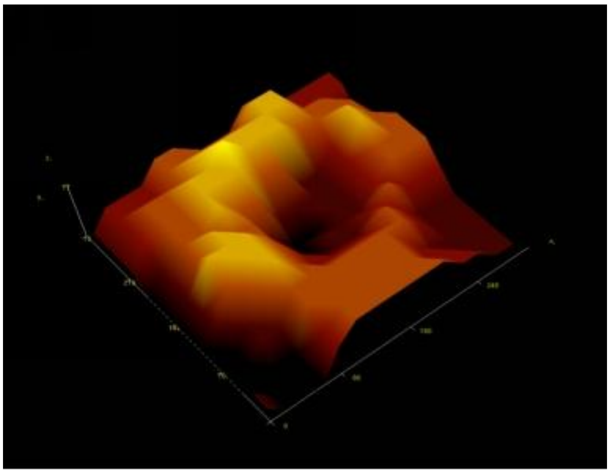


Fig. 3. Multi-angle nanoscale grooves in the top layer of $TlInS_2$ <0.1%V>.

The formation of these nanoscale grooves results from the breaking of covalent bonds in the upper layer of the surface [17]. This defect occurs during the injection of vanadium atoms [18]. The formation of nanoclusters occurs as a result of the breaking of covalent bonds in the upper layer of $TlInS_2$ and $TlInS_2$<0.1%V> crystals with γ-quanta [19].

When the covalent bonds in the top layer of $TlInS_2$ and $TlInS_2$ <0.1% V> crystals break and nanoscale grooves are formed, *In* atoms fall into the droplet and spread into the interlayer area. They are attached to the surface of the subsequent lower layer of this surface by molecular forces [5, 6]. The formation of such a small surface in $TlInS_2$ crystal has been observed from literature data [18].

Conclusion

Vanadium atoms falling into the nanoscale grooves of $TlInS_2$ crystals doped with 0.1% vanadium atoms irradiated with γ-quanta are repeatedly reflected from the walls of the nanoscale grooves and collide with each other. This increases the degree of saturation of the nanoscale grooves and the probability of molecular dissociation and the formation of critical embryos. Due to the catalytic effect of the metal, rapid formation, fusion and growth of a large number of embryos occurs. The growth of conical clusters occurs as vanadium atoms combine along the [001] surface of the $TlInS_2$ crystal.

Thus, as a result of the study of $TlInS_2$ and $TlInS_2$ <0.1%V> crystals irradiated with gamma rays by the Atomic Force Microscope method, it was determined that the effect of radiation increases the degree of saturation of nanoscale clusters, the possibility of molecular dissociation increases and causes the formation of critical embryos.

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Дослідження поверхні ван-дер-ваальса вздовж шару кристалів $TlInS_2$ і $TlInS_2$ <0,1%V>, опромінених γ-квантами

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Метою цього дослідження є визначення фундаментальних фізичних закономірностей нанопластичної деформації на поверхнях шаруватих кристалів $TlInS_2$ та $TlInS_2$, легованого 0,1% ванадію, опромінених гамма-променями, а також вивчення загальних кінетичних процесів, що впливають на їхню поверхневу структуру на нанорівні. Геометричні розміри та профілі структурних утворень у поверхневих шарах Ван-дер-Ваальса шаруватих кристалів $TlInS_2$ та $TlInS_2$ <0,1%V>, опромінених γ-квантами, були визначені за допомогою атомно-силової мікроскопії. Вплив випромінювання підвищує ступінь насичення нанорозмірних кластерів, посилює дисоціаційну здатність молекул та призводить до утворення критичних ядер. Під час каталітичної дії металу відбувається швидке утворення та ріст великої кількості нанорозмірних ядер кластерів. В результаті радіаційного впливу відбувається ріст конічних кластерів.

Ключові слова: атомна силова мікроскопія, поверхня Ван-дер-Ваальса, гістограма, профілограма, нанорозмір.