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RAMAN STUDY OF THIN-FILM AMORPHOUS SILICON DOPED WITH SILVER NANOPARTICLES

The peculiarities of the process of simultaneous magnetron sputtering on a substrate of polycrystalline silicon and silver are studied. Coatings from an amorphous silica dispersed therein with silver nanoparticles, as well aselectron microscope images and atomic force microscope images of the coatingsare obtained. Raman spectra study of the resulting films show increased scattering of the vibrational modes of amorphous silicon films with silver nanoparticles.

Keywords: amorphous silicon, silver nanoparticles, Raman scattering.

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X – RAY INTERFEROMETRIC INVESTIGATION OF STRUCTURAL DISTORTIONS IN SEMICONDUCTOR CRYSTALS UNDER THE INFLUENCE OF FAST ELECTRONS

An X-ray interferometric method for defining radiation pointed defects depending on the dose and depth of penetrating electron radiation using a three-crystal interferometer made of perfect silicon monocrystal with reflecting planes has been theoretically substantiated and experimentally realized (110). Relative deformations have been defined and the density of radiation defects depending on the radiation dose by fast electrons with energy 4,5 *MeV* has been calculated according to moiré patterns.

Keywords: interferometer, silicon monocrystal, density of radiation defects, radiation dose, moiré patterns.

1. Indroduction. Investigations of physical material properties depending on the density of different radiation defects are expedient for obtaining substances with the given properties and, in particular, for the development of radiation resistant instrumentation. Silicon crystals are especially promising.

Structural imperfections arising in crystals at irradiation are mainly point defects, which, on the average, are evenly distributed in the bulk of the irradiated crystal. The observation of these defects and their distribution by means of ordinary radiographical methods is known to be a rather difficult problem. On the other hand, X - ray interferometrical methods are highly sensitive to such defects and have high resolution. On X- ray moiré pictures it is possible to discern even minute distortions of the crystal lattice and determine the density of point defects and their change within small ranges of the matrix. Hence, having in view the investigations of imperfections formed in crystals under irradiation, we took advantage of X- ray moiré patterns.

The aim of the present work is to investigate the structural distortions in semiconductor crystals irradiated, as well as 4,5 *MeV* electrons by means of the method of diffraction moiré.

2. Electron irradiation. Radiation damages in perfect crystals due to electron irradiation are well studied by means of different techniques [1]. It should be noted, however, that such investigations in the field of dynamic scattering of X-rays in the irradiated crystals are not sufficiently studied.

Hence, the development of sensitive methods for the experimental investigation of local densities of point defects formed under radiation in crystals in general, and in semiconductor crystals in particular, is extremely urgent.

An electrical method is known for the study on the density of radiation defects in crystals, and with its help, the distribution of radiation defects in depth formed in n - type silicon at irradiation with beams of *2* to *9 MeV* electrons has approximately been determined by measurements of the resistance distribution [2].

Also well - known are the methods of X-ray diffraction and X-ray interferometry [3-6]. Besides the method of crystal swaying, all the methods of X-ray diffraction (non-interferometrical ones) are inapplicable to the study of local densities of point defects. However, for small radiation doses, the method of crystal swaying is also inapplicable for the study of local densities of point defects because of its small sensitivity and low resolution [7].

The application of interferometrical methods to the study of local densities of radiation defects is also connected with great problems [4]. In fact, to obtain appreciable interferometric effects in case of small radiation doses, it is necessary to direct the radiation perpendicular to the reflecting planes of the interferometer, as the interferometer is most sensitive to the shifts of atoms in the direction normal to the reflecting planes. The shifts of crystal lattice atoms are mostly caused by radiation fluxes also normal to the reflecting planes. Then, to study the dependence of local densities of radiation defects on the radiation dose and its penetration depth, the dimension of the irradiated crystal should be large enough.

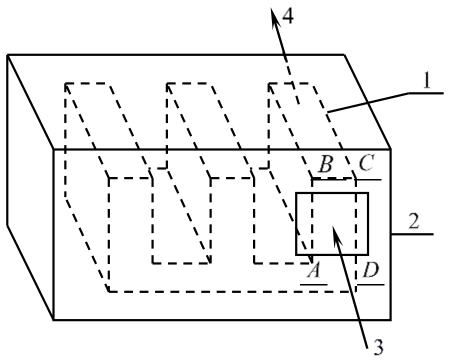


Fig. 1. The diagram of interferometer irradiation. 1-interferometer, 2- lead casing, 3- direction of electrons fluxes, 4- direction of the normal reflecting planes (110)

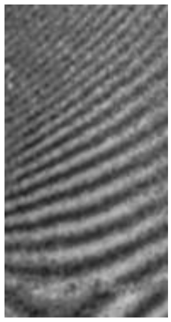
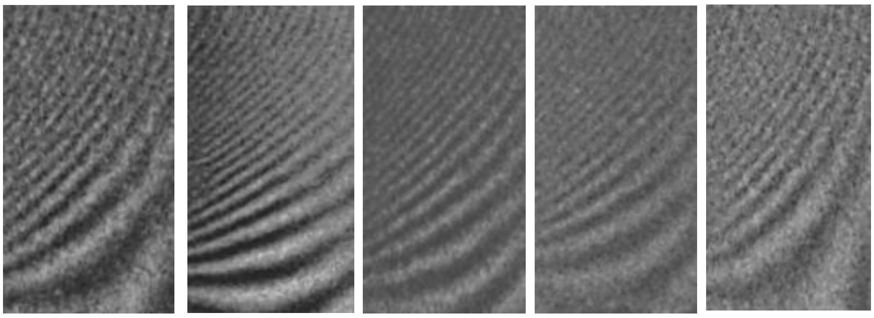


Fig. 2. The initial moiré pattern

Therefore, if the reflecting planes of the interferometer shown in Fig. 1 are ABCD planes, then the direction of radiation satisfying the mentioned requirements is direction 4 (see Fig. 1).

Structural distortions arising in semiconductor crystals at small radiation doses are so small that conventional methods of investigation prove to be inefficient. Hence, having in view the investigation of the afore-mentioned structural distortions, we took advantage of the method of X-ray diffraction moire for its sensitivity to deformations and its high resolved power. From a perfect silicon single crystal, we have constructed a three-crystal LLL - interferometer with reflecting planes (110), which were perpendicular to the working surfaces and the base of the interferometer. On obtaining the initial topogram, the third crystal of the interferometer was irradiated with fast electrons (*4,5 MeV*).The total dose was varied from $4 \cdot 10^{15}$ to $20 \cdot 10^{15}$ *electrons/cm*^{2}. In all cases the irradiation was in the direction normal to the reflecting planes of the third crystal of the interferometer, other crystals being completely shielded by special lead casing (see Fig. 1).

After each irradiation event, photos were taken to obtain moiré patterns corresponding to different radiation doses. In Fig. 2 we show the initial moiré pattern obtained from the interferometer, which was later irradiated with electrons.



a *b* *c* *d* *e*

Fig. 3. The moiré patterns obtained from the interferometer after 4.5 MeV electron irradiation for different doses a - $4 \cdot 10^{15}$, b - $8 \cdot 10^{15}$, c - $12 \cdot 10^{15}$, d - $16 \cdot 10^{15}$, e - $20 \cdot 10^{15}$ *electrons/cm*^{2}

The moiré patterns in Fig. 3a to e are from the same interferometer irradiated with different doses of 4,5 *MeV* electrons. The irradiation with electrons is seen from these figures, to lead to the change of moire patterns. With the increase in radiation dose the periods of moiré fringes are reduced (see Fig. 3 a to e), i.e., the deformation increases.

3. X - ray interferometric method for the determination of the density of radiation (point) defects in crystals. It should be noted that in all the mentioned and generally known (X-ray) interfcrometric investigations of crystal imperfections, no technique developed for the determination of the density of point defects was used.

Our purpose here is to theoretically substantiate and apply an X- ray interferometric method to the determination of the density of radiation point defects depending on the dose and penetration depth of radiation.

The change in the crystal volume as a result of deformation could be expressed as follows [6]:

$$\Delta V = \frac{1}{3K}\int \vec{r}\vec{f}dV, \tag{1}$$

where K is the factor of all-round compression of the crystal, $\vec{f}$ is the vector of the density of volume forces exerted on the crystal. As the irradiation leads to an increase in Frenkel defects (point defects), then, if we know $\vec{f}$ due to these defects, we can calculate the change in the volume and, hence, the change in the lattice parameter. Using the value of relative deformation determined in advance from experiments, one can calculate the density of radiation defects.

In elasticity theory, the interstitial atoms (vacancies) produce elastic fields which are described by the density of forces [8]

$$f(\vec{r}) = -K\Omega_0 grad\delta(\vec{r}). \tag{2}$$

If we substitute (2) into (1), then

$$\Delta V = -\frac{1}{3}\Omega_0\int \vec{r} grad\delta(\vec{r})dV = \frac{1}{3}\Omega_0\int \mathrm{div}\vec{r}\delta(\vec{r})dV = \Omega_0. \tag{3}$$

Hence, the value of Ω_0 is the increase in the crystal volume due to the presence of one interstitial atom. One can show [1] that N such point defects producing deformation according to (2) give a cubic expansion ΔV determined b

$$\Delta V = 12\pi\frac{1-\nu}{1+\nu}\cdot\frac{N}{V}C, \tag{4}$$

where C is a constant having the dimension of the volume and of the order of magnitude of the atomic volume characterizing the "power" of the defect, ν is the Poisson factor. The relative variation of the lattice parameter could be expressed as

$$\frac{\Delta d}{d} = \frac{1}{3}\frac{\Delta V}{V} = 4\pi\frac{1-\nu}{1+\nu}\cdot\frac{N}{V}C. \tag{5}$$

Thus, using (5) and calculating the relative deformation one can estimate from the moiré patterns the local density of radiation defects, $N/V = N_D$.

From the topograms of Fig. 3a to e, the distributions of the intensities of moiré fringes in definite directions are obtained, and distances between maxima are measured by means of microphotometry. In all cases the measurements are taken only between definite maxima and, in this way, the values of relative deformation $\Delta d/d$ corresponding to different radiation doses are calculated.

Dependence of the density of radiation defects on the radiation dose.

Solving (5) with respect to $N/V = N_D$ we have

$$N_D = \left(\frac{1+\nu}{1-\nu}\right)\frac{\Delta d/d}{4\pi C}. \tag{6}$$

If we substitute the experimental values $\Delta d/d$ corresponding to different doses into (6), then taking into account that $C \approx 10^{-24}$ *cm*^{3} and $\nu = 0.262$, we obtain the dependence of the density of radiation defects on the radiation dose. The results are given in the Table.

Table

Radiation dose *(electrons/ cm*^{2}*)*	$4 \cdot 10^{15}$	$8 \cdot 10^{15}$	$12 \cdot 10^{15}$	$16 \cdot 10^{15}$	$20 \cdot 10^{15}$
Relative deformation	$1.54 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	$3.08 \cdot 10^{-7}$	$4.18 \cdot 10^{-7}$	$5.5 \cdot 10^{-7}$
Density of radiation defects (*cm*$^{-3}$)	$2.1 \cdot 10^{16}$	$3.0 \cdot 10^{16}$	$4.2 \cdot 10^{16}$	$5.7 \cdot 10^{16}$	$7.5 \cdot 10^{16}$

The local density of radiation defects is seen to increase with the radiation dose.

The dependence of the defect density on the penetration depth of *4,5 MeV* electrons in the crystal is studied, and it is seen that the density of defects is reduced as electrons go deeper into the analyzer crystal of the interferometer.

In view of the afore-said we come to the following conclusion:

1. With the help of the method of X- ray diffraction, the moiré structural distortions are observed, which arise at the irradiation of the analyzer crystal with *4.5 MeV* electrons.

2. Using the relative deformation determined from the obtained topograms, one can estimate both the local density of point defects and their dependence on the penetration depth of electrons at different radiation doses.

3. The developed method could be used, in particular, for determining the density of radiation (point) defects in crystals both in scientific research and in the production of semiconductor devices.

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Ա.Հ. ԱԲՈՅԱՆ

ԿԻՍԱՀԱՂՈՐԴՉԱՅԻՆ ԲՅՈՒՐԵՂՆԵՐՈՒՄ ԱՐԱԳ ԷԼԵԿՏՐՈՆՆԵՐՈՎ ԱՌԱՋԱՑԱԾ ԿԱՌՈՒՑՎԱԾՔԱՅԻՆ ԱՂԱՎԱՂՈՒՄՆԵՐԻ ՌԵՆՏԳԵՆԱԻՆՏԵՐՖԵՐԱՉԱՓԱԿԱՆ ՀԵՏԱԶՈՏՈՒԹՅՈՒՆԸ

Տեսականորեն հիմնավորվել և փորձնականորեն իրականացվել է ռադիացիոն կետային արատների որոշման ռենտգենաինտերֆերաչափական մեթոդ՝ կախված էլեկտրոնային ճառագայթման բաժնեչափից և թափանցման խորությունից՝ օգտագործելով սիլիցիումի կատարյալ միաբյուրեղից պատրաստված (110) անդրադարձնող հարթություններով եռաբյուրեղ ինտերֆերաչափ: Ըստ Մուարի պատկերների՝ որոշվել են հարաբերական դեֆորմացիաները, որոնց կիրառումով որոշվել է ռադիացիոն արատների խտությունը՝ կախված 4,5 *ՄէՎ* էներգիայով արագ էլեկտրոններով ճառագայթման բաժնեչափից:

Առանցքային բառեր. ինտերֆերաչափ, սիլիցիումի միաբյուրեղ, ռադիացիոն արատների խտություն, ճառագայթման բաժնեչափ, Մուարի պատկերներ:

А.О. АБОЯН

РЕНТГЕНОИНТЕРФЕРОМЕТРИЧЕСКОЕ ИССЛЕДОВАНИЕ СТРУКТУРНЫХ НАРУШЕНИЙ, ВОЗНИКАЮЩИХ В ПОЛУПРОВОДНИКОВЫХ КРИСТАЛЛАХ ПОД ДЕЙСТВИЕМ БЫСТРЫХ ЭЛЕКТРОНОВ

Теоретически обоснован и экспериментально реализован рентгеноинтерферометрический метод определения плотности радиационных точечных дефектов в зависимости от дозы и глубины проникновения электронного облучения с использованием трехкристального интерферометра, изготовленного из совершенного монокристалла кремния с отражающими плоскостями (110). По муаровым картинам определены относительные деформации и вычислена плотность радиационных дефектов в зависимости от дозы облучения быстрыми электронами энергией 4,5 *МэВ.*

Ключевые слова: интерферометр, монокристалл кремния, плотность радиационных дефектов, доза облучения, муаровые картины.

УДК 661.681

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ЭФФЕКТЫ НЕКОЛЛИНЕАРНОСТИ В ОДНОМЕРНОМ СПИН-ЗАВИСИМОМ РАССЕЯНИИ

Решена задача 1D – рассеяния спин-поляризованной волны на финитном барьере. Векторы поляризации падающей волны и намагниченности барьера, вообще говоря, не располагаются в одной плоскости. Исследованы зависимости поляризации рассеянных волн от степеней свободы, определяющих ориентацию намагниченности барьера.

Ключевые слова: спин-поляризованная волна, конечный магнитный барьер, спин-зависимое рассеяние, коэффициенты прохождения и отражения, переориентация вектора поляризации.

1. Известные спинтронные явления – GMR, TMR. Valve effect и т.д. [1-3] – обусловлены спин-зависимым транспортом. Общность систем, в которых они проявляются, это существование в них выделенных направлений, обусловливающих появление новых магнитных и спиновых степеней свободы. Одним из примеров может служить система, содержащая два магнитных слоя нанотолщины. Потенциальный профиль ее содержит два магнитных барьера с неколлинеарными намагниченностями [4]. Система обладает всеми указанными выше свойствами. Кроме того, в ней возможен эффект, аналогичный известному в оптике эффекту Малюса: неколлинеарность намагниченностей приводит к тому, что в резонансе прохождения должны проявляться ярко выраженные модуляционные эффекты. В [5] рассмотрена аналогичная, но более простая система, состоящая из одного