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DEVELOPING A TECHNOLOGY FOR OBTAINING HYDROGEN ENERGY RAW MATERIALS THROUGH SOLAR ENERGY

It is shown that with an increase in amorphous films Si and TiO_X on the surface of the glass at a frequency of 13.5 MHz and under the influence of solar energy on the TiO_X membrane, water molecules break down into hydrogen and oxygen gases. At studying the efficiency of the process, it is revealed that it is possible to increase it when the rutile is restored by non-thermal treatment, causing additional defects, but with the help of a vacuum chamber, where it is necessary to introduce a certain number of pure oxygen atoms:

Keywords: solar energy, hydrogen raw materials, photoelectrode, photoelectrochemical conversion.

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SCREENED IMPURITY SCATTERING RELAXATION TIME WITH THE QUANTUM WELL/HIGH-κ DIELECTRIC HETEROJUNCTION

The screened impurity scattering probability is calculated in the presence of quantum well (QW) / high-κ dielectric heterojunction. It is found that: *a*) for the large values of quasi-two dimensional screening radius the QW/high-κ dielectric mismatch effect balances the influence of 2D screening, *b*) for the presented case the scattering relaxation time dependence from the electron energy is more strong than in the QW/low-κ dielectric type heterostructure case, *c*) the scattering relaxation time strongly depends on the QW thickness. The screened impurity scattering relaxation time numerical analysis for the realistic $InSb/HfO_2$ interface was performed.

Keywords: quantum well, high-κ dielectric, impurity scattering.

As it is known the narrow band gap III–V group semiconductors are reliable candidates for optoelectronic applications because modulation-doped heterostructures on their base provide high carrier mobility of samples. This key parameter determines the power switching high-speed and dissipation of optoelectronic devices, and the suitable design of the dielectric environment can essentially enhance the carrier mobilities in these nanosytems. In particular, for InSb based quantum well located in close proximity to dielectric substrates ($InSb/Al_xIn_{1-x}Sb$), the carrier mobilities $3.24.10^5$ cm^2 V^{-1}s^{-1}(T = 2 K) and $4.4.10^4$ cm^2 V^{-1} s^{-1}(T = 300 K) were extracted [1]. The availability of a wide class of dielectric barrier materials with relatively high dielectric constants (high-κ dielectrics) opens up additional prospects for increasing the mobility of samples, for which the Coulomb scattering of mobile charges particularly on ionized impurities should be reduced.

At present, the utilization of III-V group semiconductors combined with high-κ dielectric materials (HfO_2, ZrO_2,) correspondingly as the quantum well (QW) and barrier media among the post-silicon alternatives of current quasi-two dimensional (Q2D) systems is quite justified [2]. In this regard, an investigation of the physical properties of such systems is really important due to their significance both in scientific interest and optoelectronic needs including photodetectors, sensors.

The intensive study is carried out in recent time related to electronic, optical and transport phenomena in aforementioned systems ([3] and Refs. therein). In particular, the effect of QW/high-κ dielectric barrier media dielectric mismatch on the impurity states screened by Q2D EG is studied in [4] where for the high-κ dielectric barrier/QW/high-κ dielectric dielectric barrier, (*hh-κ*) type of the QW heterostructure is established that at the moderately large (relative to the QW width d) in-plane distances an impurity screened interaction is characterized by Q2D Debye-Hückel potential demonstrating a restore of the screening radius parameter - atypical in the framework of the direct 2D screening theory.

In this paper by using the Q2D Debye-Hückel potential as an integral result of quantum confinement (QC), QW/high-κ dielectric mismatch and impurity screening effects balanced influence under the requested distances the QW screened background impurity scattering relaxation time has been investigated for the first time.

Consider a semiconductor QW with the dielectric constant ε_w and neighboring with the barrier media having the dielectric constants $\varepsilon_{b1,2}$. In the discussed model, only the n-type Q2D charged channel with the average surface density n_S contributes to the impurity center screening. For such QW heterostructure QC and high κ-dielectric barrier effects are characterized by conditions $a_0 >> d$ and $\varepsilon_r = \varepsilon_w / \varepsilon_b < 1$, respectively, where the Bohr radius is $a_0 = \varepsilon_w \hbar^2 / m_e e^2$, m_e – is the electron effective mass. So that a gas of carriers is confined to move in the x-y plane, i.e., their motion in the z direction which is taken as the direction perpendicular to the plane of the charged channel is confined. Necessarily, we also assume that the QW thickness d is small compared with the Debye radius for bulk samples as $r_D >> d$.

In this condition for the appropriate range of effectively moderately large 2D distances

$$d \ll \rho < \left(\frac{2\rho_S}{d}\right)\left(\frac{d}{2\varepsilon_r}\right)\left(\left(\frac{e^3+1}{e^3-1}\right)^2 - \varepsilon_r^2\right)^{1/2}, \tag{1}$$

the screened background impurity interaction potential $V_S(\rho)$ takes the following Q2D form [4]

$$V_S^{hh-k}(\rho) = -\frac{e^2}{\varepsilon_w}\frac{\exp(-\rho/\rho_S)}{\rho}, \tag{2}$$

where $e = 2.718..$- is the natural number, ρ_s - the Q2D screening radius as

$$\rho_S = \sqrt{\frac{d}{2q_S}}. \tag{3}$$

In Exp. (3), for the degenerate and non-degenerate 2D EG statistics under the condition of the size quantum limit, i.e. when the one-particle ground quantum level in QW is occupied only, the screening parameter q_S correspondingly takes the forms:

$$q_S = \frac{2}{a_0}, \left(\frac{\pi n_S \hbar^2}{m_e k_B T} \gg 1\right) \tag{4}$$

and

$$q_S = \frac{2}{a_0}\frac{\pi n_S \hbar^2}{m_e k_B T}, \left(\frac{\pi n_S \hbar^2}{m_e k_B T} \ll 1\right). \tag{5}$$

Exp.(2) is received in the leading order of the parameter d / a_0 which permits to get a solution for any arbitrary normalized charge distribution function in z direction.

The scattering rate due to the scattering of carriers by background impurities in the relaxation time approximation is given by [5, 6]

$$\frac{1}{\tau} = \frac{2\pi}{\hbar}\sum\nolimits_{\vec{k},\vec{k}'} N_V \left|M_{\vec{q}}\right|^2 (1 - cos\theta)\, \delta(E_{\vec{k}'} - E_{\vec{k}}), \tag{6}$$

where $\vec{q} = \left|\vec{k}' - \vec{k}\right|$ is the difference between the initial and final wave vectors of scattered electron in QW plane, θ - the electron scattering angle as $\theta = \vec{k}'\vec{k}/\left|\vec{k}'\right|\left|\vec{k}\right|$, $E_{\vec{k}}$ - the energy of two-dimensional motion, N_V - the density of ionized impurities.

In Exp. (6), the matrix element of scattering $M_{\vec{q}}$ is defined by means of the screened Coulomb interaction potential Fourier component related to the QW region as:

$$M_{\vec{q}} = \frac{2\pi e^2}{\varepsilon_w S}\frac{1}{\sqrt{q^2 + \rho_S^{-2}}}, \tag{7}$$

where S is the normalizing area in the QW plane.

After substituting Exp.(7) in Exp.(6), for the scattering probability we obtain:

$$\frac{1}{\tau} = \frac{2N_S\pi^2 m_e e^4}{\varepsilon_w^2 \hbar^3}\frac{1}{k^2}\left[1 - \frac{1}{\sqrt{1+(2k\rho_S)^2}}\right], \tag{8}$$

where $N_S = N_V/d$ is the density of ionized impurity scattering centers per unit area of the QW.

Corresponding to Exp.(1), the electron wave vector obeys the validity criteria related to the moderately small *k* vector's range as:

$$\frac{1}{d} \gg k > \left(\frac{\varepsilon_r}{\rho_S}\right)\left(\left(\frac{e^3+1}{e^3-1}\right)^2 - \varepsilon_r^2\right)^{1/2}. \tag{9}$$

Finally for the QW impurity scattering probability expressed by the energy of 2D motion $E_{\vec{k}} = \frac{\hbar^2 k^2}{2m_e}$, we get

$$\frac{1}{\tau} = \frac{N_S\pi^2 e^4}{\varepsilon_w^2 \hbar}\frac{1}{E_{\vec{k}}}\left[1 - \frac{1}{\sqrt{1+\frac{4m_e d}{\hbar^2 q_S}E_{\vec{k}}}}\right]. \tag{10}$$

The most characteristic features of Exp. (10) are:

a) as we can see from Exp. (8), for the large values of the $k\rho_S$ parameter, Exp. (10) goes to the electron energy dependence $\frac{1}{\tau} \sim \frac{1}{E_{\vec{k}}}$ [5], corresponding to the limit of no 2D screening in dielectrically homogenous QW structure, indicating that here the QW/high-κ dielectric mismatch effect balances the influence of the 2D screening;

b) the scattering relaxation time for the presented QW/hh-κ dielectric mismatch case depends on the electron energy $E_{\vec{k}}$ more strongly than in the low-κ dielectric barrier/QW/low-κ dielectric dielectric barrier (QW/low-κ) type QW heterostructure case [6], for which $\frac{1}{\tau} \sim \left(1 + aE_{\vec{k}}\right)^{-3/2}$, where a depends on the material parameters;

c) the scattering relaxation time here as similar to the QW/low-κ dielectric mismatch effect case [6] strongly depends on QW thickness *d*.

As an illustration of the offered theoretical model, let us now carry out the impurity scattering time numerical calculations for the realistic InSb/HfO$_2$ interface [2], for that the dielectric constants ratio $\varepsilon_r = \varepsilon_w / \varepsilon_b = \varepsilon_{InSb} / \varepsilon_{HfO2} \approx 16.8 / 25 = 0.625$ value is taken. InSb bulk sample holds the smallest electron effective mass ($m^* \approx 0.014 m_0$, m_0 - is the free electron mass)) and a macroscopically large impurity effective Bohr radius as $a_0 \approx 63.7$nm. In accordance with the strong QC condition $a_0 \gg d$, we will display a numerical data for the QW width values $d < 10$ nm.

In Figs.1 and 2 are shown impurity scattering time dependences as a function of kd parameter for fixed n_s/T and QW width values in accordance with Exps. (8) and (3).

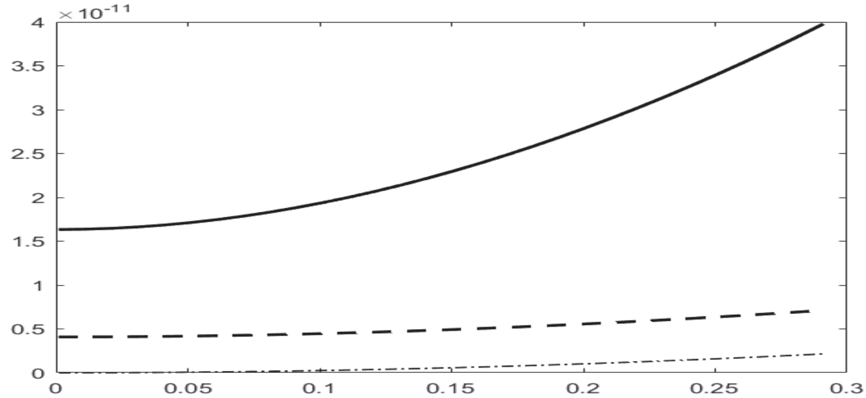

Fig. 1. Impurity scattering relaxation time τ as a function of kd parameter for the fixed QW width values of d_1 = 5nm (solid line) , d_2 = 10 nm (dashed line) for the $HfO_2/InSb/HfO_2$ hh- κ type QW structure with the nondegenerate 2D EG screening ($n_s/T = 1.5.10^8$ $cm^{-2}/^0K$). The graphical line corresponding to no 2D screening case in dielectrically homogenous QW structure is presented as well (dashed-dotted line)

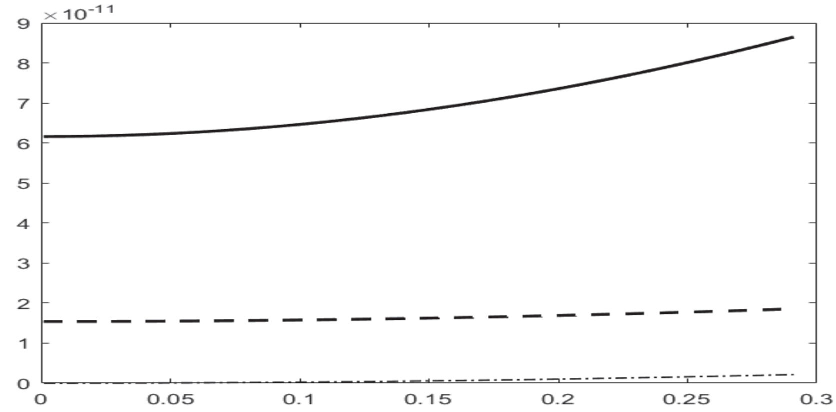

Fig. 2. Impurity scattering relaxation time τ as a function of kd parameter for the fixed QW width values of d_1 = 5nm (solid line) , d_2 = 10 nm (dashed line) for the $HfO_2/InSb/HfO_2$ hh- κ type QW structure with the degenerate 2D EG screening ($n_s/T = 2.10^9$ $cm^{-2}/^0K$). The graphical line corresponding to no 2D screening case in dielectrically homogenous QW structure is presented as well (dashed-dotted line)

As we see from the graphs, at the certain characteristic values of QW width the impurity scattering relaxation time τ increases with the enhancement of the scattered particle wave vector and consequently of the energy. This enhancement, as follows from Figs.1 and 2, is stronger for the degenerate 2D EG screening case ($n_s/T = 2.10^9$ $cm^{-2}/{}^0K$ with ρ_S= 9.1.10^{-7} cm). In particular, for the $d_1 = 5nm$ the scattering relaxation time τ starts from the value of τ= 6.1.10^{-11}s in deeply long wave limit whereas an analogous result for the nondegenerate 2D EG screening case (n_s/T = 1.5.10^8 $cm^{-2}/{}^0K$ with ρ_S= 1.8.10^{-6} cm) is τ= 1.3.10^{-11}s. At the same time, the enhancement rate for the nondegenerate case is higher than in degenerate case. For the large values of QW width ($d_2 = 10$ nm), such enhancement softens already in both cases and the ionized impurity scattering strengthening takes place.

On the other hand, the presented graphical results show that suppression of ionized impurity scattering is taking place for the large values of n_s/T parameter and therefore for the small values of Q2D screening radius ρ_S.This is due to the weakening of impurity potential when passing from the nondegenerate 2D EG screening case to the degenerate in accordance with Exps. (2-5).

The suppression of ionized impurity scattering also occurs with a decrease in the QW width. Such behavior in the SQL is due to the dependence of the cross section for scattering by ionized impurities on the carriers energy when the latter increases as the width of the layer decreases. For that case the scattering cross section decreases with the increase of the particle energy.

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ԷԿՐԱՆԱՎՈՐՎԱԾ ԽԱՌՆՈՒԿԱՅԻՆ ՑՐՄԱՆ ՎԵՐԱԿԱՆԳՆՄԱՆ ԺԱՄԱՆԱԿԸ ՔՎԱՆՏԱՅԻՆ ՓՈՍ/ԲԱՐՁՐ- к ԴԻԷԼԵԿՏՐԻԿ ՀԵՏԵՐՈԱՆՑՄԱՆ ՀԱՇՎԱՌՄԱՄԲ

Հաշվարկված է էկրանավորված խառնուկային ցրման հավանականությունը քվանտային հոր / բարձր-к դիէլեկտրիկ հետերոանցման առկայությամբ: Գտնվել է, որ. ա) քվազի երկչափ էկրանավորման շառավղի մեծ արժեքների դեպքում քվանտային հոր / բարձր-к դիէլեկտրական անհամապատասխանությունը հավասարակշռում է երկչափ էկրանավորման ազդեցությունը, բ) ներկայացված դեպքում ցրման վերականգնման ժամանակի կախվածությունը էլեկտրոնի էներգիայից ավելի ուժեղ է, քան քվանտային հոր /ցածր-к տիպի դիէլեկտրական հետերոկառուցվածքի դեպքում, գ) ցրման վերականգնման ժամանակը խստորեն կախված է քվանտային հորի հաստությունից: Իրական InSb/HfO₂ հետերոմակերևույթի առկայությամբ կատարված է ցրման վերականգնման ժամանակի թվային վերլուծություն:

Առանցքային բառեր. քվանտային հոր, բարձր-к դիէլեկտրիկ, խառնուկային ցրում:

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ВРЕМЯ РЕЛАКСАЦИИ ЭКРАНИРОВАННОГО ПРИМЕСНОГО РАССЕЯНИЯ С ГЕТЕРОПЕРЕХОДОМ КВАНТОВАЯ ЯМА/ВЫСОКИЙ-к ДИЭЛЕКТРИК

Рассчитана вероятность экранированного примесного рассеяния в присутствии гетероперехода квантовая яма (КЯ)/высокий-к диэлектрик. Выявлено, что: а) при больших значениях радиуса квазидвумерного экранирования диэлектрический разрыв типа КЯ/высокий-к диэлектрик балансирует влияние двумерного экранирования; б) для представленного случая зависимость времени релаксации рассеяния от энергии электронов более сильное, чем в случае гетероструктуры КЯ/низкий-к диэлектрик; в) время релаксации рассеяния сильно зависит от толщины КЯ. Выполнен численный анализ времени релаксации экранированного примесного рассеяния для реалистичной гетерограницы InSb/HfO_2.

Ключевые слова: квантовая яма, высокий-к диэлектрик, примесное рассеяние.