International Journal of Advanced Research in Physical Science (IJARPS)
Volume 2, Issue 3, March 2015, PP 22-33
ISSN 2349-7874 (Print) & ISSN 2349-7882 (Online)
www.arcjournals.org

Relaxed Optics: Necessity of Creation and Problems of Development

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Abstract: *Necessity of creation and problems of development of Relaxed Optics are discussed. Basic concepts of this chapter of modern physics (phenomenological chronological classification of processes of interaction light and matter and classification which based on expansion in series of generalizing Pointing vector of electromagnetic field) are analyzed. Electro-physical and structural experimental data and proper models are represented. Perspectives of application and development of Relaxed Optical processes and phenomena are discussed too.*

Keywords: *Relaxed Optics, Pointing tensor, laser implantation, irreversible phenomena, Nonlinear Optics.*

1. INTRODUCTION

Relaxed Optics (RO) is the chapter of modern physics of irreversible interaction light and matter [1,2]. Necessity of creation RO is caused of technological applications of laser radiation (laser annealing, laser implantation and other [1,2]). Phenomenological energy-time classification of processes and phenomena is basis of RO. According to this classification we have three types of processes and phenomena: kinetic (mainly quantum first-order processes); dynamic (mainly wave second-order processes) and mixing kinetic-dynamic or dynamic-kinetic processes. Roughly speaking RO is the synthesis Quantum Electronics, Nonlinear Optics, Physical Chemistry, Radiation Physics of Status Solid, Physics of Irreversible Phenomena in one system.

For bond RO and Nonlinear Optics expansion in series of generalizing Pointing vector by steps of electric and magnetic fields was used. In this case we have tensor product of electric and magnetic tensors series. This product was used for the classification of proper phenomena. Real part is corresponded to linear and nonlinear optical phenomena, complex part – relaxed optical phenomena [2]. It is allow searching new classes matter with magnetic and electrical properties for observation proper phenomena [2].

RO allowed to explain the role and influence of spectral, time and energy characteristics of laser irradiation on generation of irreversible changes in irradiated matter [1,2]. This approach was used for the analysis all processes of interaction laser radiation and solid (from luminescence to melting) [1,2] with help cascade physical-chemical model of excitation in the regime of saturation.

Interference and diffractive phenomena of RO may be observed with help plasma models [2]. Circular and elliptic polarizations of irradiation allow generating homogeneous surface nanostructures. Here height is changed from 15-20 nm for nanosecond regime of laser irradiation [3] to 400-450 nm for femtosecond regime [4].

For “bulk” case of irradiation the phenomena of self-focusing and self-trapping are basic for the creation of irreversible changes in the bulk of irradiated materials. Influence of polarization of irradiation on these processes isn’t observed [2,4]. Generation of “bulk” laser-induced damages may be represented with help theory of streamer discharge [5] and Prokhorov-Lugovoy theory of moving focuses [6].

Methods of RO may be used for the observation nonlinear optical processes in self-absorption range of spectrum [2]. In this case we have laser-induced phase transformations in irradiated matter.

Development of RO is caused of further minimization of sizes of elements of optoelectronic systems and creation new experimental and theoretical methods for resolution of this problem.

2. Basic Concepts

According to [1, 2] the basic relaxed optical phenomena may be classified as kinetic, dynamic and mixed (see Table 1).

The kinetic irreversible phenomena are the classical quantum phenomena.

The dynamic irreversible phenomena are collective effects. It are not local effects, it are effects of long-range action. Quantum effects in this case are unimportance.

The mixing irreversible phenomena are included the combination of the kinetic and dynamic phenomena: among them – the laser annealing and laser implantation of solid. Mathematically these phenomena are written with help the kinetic functional or differential equations; among them equations of diffusion, transfer, heat conductivity and other.

Table1. *The basic relaxed optical phenomena [1].*

Kinetic phenomena	Dynamic phenomena	Mixed irreversible phenomena
1. τ, τ' >,>> τ_h,τ_r photochemical processes, not including $N_f \geq N_s$ 2. $\tau_0 < \tau_h$; $\tau_h < \tau' < \tau_r$; $\tau > \tau_r$ \; $h\nu > E_g$ – the creation of optical defects 3. $\tau > \tau_h,\tau_r$; $N_f << N_s$ – classical photochemical processes	4. $\tau_0 < \tau_h$; $\tau < \tau_i,\tau_r$ irreversible phenomena, nonlinear optics, interference phenomena 5. $\tau_0 > \tau_h,\tau_r$; $N_f \leq N_s$ dynamic generation the underthreshold defects, Yan-Teller effect, photoplastic effect 6. $\tau_0 > \tau_h,\tau_r$; N_f >,>> N_s melting, the heating destruction of solid and other	7. Laser annealing of solid: a) $\tau_0 < \tau_h$; $\tau > \tau_r$; $E_a \leq h\nu \leq E_g$ phenomena 1 and 3; when $\tau_0 > \tau_h,\tau_r$ – phenomena 5 and 6; b) $h\nu > E_g$ – phenomena 2 and 5 8. Laser implantation and effects of optical switching in thin films – the mixture phenomena 1-6

The basic phenomenological parameters for RO are next (Table 1). Chronological parameters [1, 2]: τ_i – the time of irradiation; τ_h – the time of the chaotization, practically the time of the transition the elementary act of the excitation with short-range action to long-range action; τ_r – the dynamic (practically in general case thermodynamic) time of the system relaxation; τ, τ' - the time of life the excitation phase in equilibrium and nonequilibrium states respectively; τ_0 – the time of the creation the irreversible changing in solid; τ_l – the time of optical excitation. The energetic characteristics of this approach are next [1, 2]: E_g – the energy of band gap; E_a – the energy of the activation the optical scattering center, including the energy of ionization of proper center; $h\nu$ – the energy of photon. The concentration characteristics are: N_f – the density of light flow; N_s – the density of the scattering centers. Geometrical parameter is σ_s – the corresponding section of light scattering.

This classification is rough but it allows explaining basic processes and phenomena of RO.

The basic distinction between NLO and RO is caused of the difference of mechanisms of relaxation of optical excitation. In Nonlinear Optics the basic mechanisms are radiated [2]; in Relaxed Optics are non-radiated [2]. NLO is based on the series expansion the real part of dielectric permittivity tensor of irradiated matter as steps of electric field [7]. This concept is used for the classic nonlinear optical processes and phenomena with value of permeability $\mu = 1$. Series expansion of magnetic permeability tensor is used for magnetic materials. But some materials (indium animonide, indium arsenide, $Hg_xCd_{1-x}Te$ a.o.) have values of permittivity and permiability 10-20. Therefore for modeling of NLO and RO processes in these materials we must used tensor product of permittivity and permeability tensors. This tensor product may be represented as coefficient of generalizing Pointing vector or Pointing tensor Π_{ij} , which must be represented as tensor product electric-flux density D_i and magnetic flux density B_j

$$\Pi_{ij} = D_i \times B_j, \tag{1}$$

where $D_i = \varepsilon_{ij} E_j$ and $B_j = \mu_{ij} H_j$.

Permittivity and permeability tensors may be represented in next forms

$$\varepsilon_{ij} = \varepsilon_{ij}^1 + i\varepsilon_{ij}^2 + \left(\varepsilon_{ijk}^1 + i\varepsilon_{ijk}^2\right)E_k + \left(\varepsilon_{ijkl}^1 + i\varepsilon_{ijkl}^2\right)E_k E_l + \dots \tag{2}$$

and

$$\mu_{ij} = \mu_{ij}^1 + i\mu_{ij}^2 + \left(\mu_{ijk}^1 + i\mu_{ijk}^2\right)H_k + \left(\mu_{ijkl}^1 + i\mu_{ijkl}^2\right)H_k H_l + \dots \tag{3}$$

After regrouping terms equations (1.45) and (1.46) have next form

$$\varepsilon_{ij} = \left(\varepsilon_{ij}^1 + \varepsilon_{ijk}^1 E_k + \varepsilon_{ijkl}^1 E_k E_l + \dots\right) + i\left(\varepsilon_{ij}^2 + \varepsilon_{ijk}^2 E_k + \varepsilon_{ijkl}^2 E_k E_l + \dots\right) \tag{2a}$$

and

$$\mu_{ij} = \left(\mu_{ij}^1 + \mu_{ijk}^1 H_k + \mu_{ijkl}^1 H_k H_l + \dots\right) + i\left(\mu_{ij}^2 + \mu_{ijk}^2 H_k + \mu_{ijkl}^2 H_k H_l + \dots\right). \tag{3a}$$

Where $\varepsilon_{ij}^1, \varepsilon_{ij}^2, \varepsilon_{ijk}^1, \varepsilon_{ijk}^2, \varepsilon_{ijkl}^1, \varepsilon_{ijkl}^2$ are real and imagine parts of proper terms of permittivity tensor and, $\mu_{ij}^1, \mu_{ij}^2, \mu_{ijk}^1, \mu_{ijk}^2, \mu_{ijkl}^1, \mu_{ijkl}^2$ are real and imagine parts of proper terms of permeability tensor, E_k – electric field strength, H_k – magnetic field strength.

The representation of permittivity and permeability in forms (2) and (3) allow including the influence of induced electric and magnetic properties of matter on corresponding physical characteristics.

For explanation of interference between Nonlinear and Relaxed optical phenomena expansion in series of Pointing tensor by step of electric and magnetic fields is used [2]. Real and imagine parts of Pointing tensor coefficients have next form [2]

$$\begin{aligned} &\mathrm{Re}\left(\varepsilon_{ij} \times \mu_{ij}\right) = \\ &= \left(\varepsilon_{ij}^1 + \varepsilon_{ijk}^1 E_k + \varepsilon_{ijkl}^1 E_k E_l + \dots\right) \times \left(\mu_{ij}^1 + \mu_{ijk}^1 H_k + \mu_{ijkl}^1 H_k H_l + \dots\right) - \\ &- \left(\varepsilon_{ij}^2 + \varepsilon_{ijk}^2 E_k + \varepsilon_{ijkl}^2 E_k E_l + \dots\right) \times \left(\mu_{ij}^2 + i\mu_{ijk}^2 H_k + \mu_{ijkl}^2 H_k H_l + \dots\right), \end{aligned} \tag{4}$$

$$\begin{aligned} &\mathrm{Im}\left(\varepsilon_{ij} \times \mu_{ij}\right) = \\ &= \left(\varepsilon_{ij}^1 + \varepsilon_{ijk}^1 E_k + \varepsilon_{ijkl}^1 E_k E_l + \dots\right) \times \left(\mu_{ij}^2 + \mu_{ijk}^2 H_k + \mu_{ijkl}^2 H_k H_l + \dots\right) + \\ &+ \left(\varepsilon_{ij}^2 + \varepsilon_{ijk}^2 E_k + \varepsilon_{ijkl}^2 E_k E_l + \dots\right) \times \left(\mu_{ij}^1 + \mu_{ijk}^1 H_k + \mu_{ijkl}^1 H_k H_l + \dots\right). \end{aligned} \tag{5}$$

Formulas (4) and (5) are represented symmetrical properties of irradiated matter therefore it may be interpreted as “tensor” coefficients of Pointing tensor.

The real (4) and imagine (5) parts of tensor products and selected terms of these series may be used for the phenomenological interpretation and prognostication of mixed phenomena of Relaxed Optics. It may be cooperative electric and magnetic phenomena, including dynamical ferromagnetic, ferroelectric and superconductivity phenomena. Special interest is caused the incommensurate mixed phenomena: for example, electric dipole – magnetic quadruple or contrary.

These phenomena are depended from intensity of irradiation. Each term in expressions (4) and (5) is corresponded to proper light-induced phenomenon. Rough classifications of possible phenomena, which is based on the expansions (4) and (5), are represented in Tables 2 and 3 [2].

Processes and phenomena of Table 2 are phenomena of Linear and Nonlinear Optics. Each term of (4) is corresponded of proper process or phenomenon. Nonlinear optical phenomena may be represented as non-equilibrium phase transitions [8-10]. The time of these transitions is equaled the time of proper nonlinear process or phenomenon.

Table2. *Basic types of possible phenomena, which is based on the expansion in series of* $\mathrm{Re}(\varepsilon_{ij} \times \mu_{ij})$.

Type of phenomena	Radiative processes		
	$\sim E_i...E_j$	$\sim H_i...H_j$	$\sim E_i...H_j$
First order processes (term with sign "+" in (1))	Pure electrooptical processes, including Pockels and Kerr phenomena	Pure magnetooptical processes, including Faradey effect	Mixing electro and magnetooptical processes
Second order processes (term with sign "–" in (1))	Reradiative electrooptical induced processes	Reradiative magnetooptical induced processes	Reradiative electrooptical and magnetooptical induced processes
Multi-order (N) processes	N–reradiative electrooptical induced processes	N–reradiative magnetooptical induced processes	N–reradiative electrooptical and magnetooptical induced processes

Processes and phenomena, which are represented in Table 3, are non-radiated irreversible processes [2]. Therefore here must be represented the imagine part of Pointing tensor.

This concept allow to unite processes and phenomena of Nonlinear Optics, including parametrical Crystal Optics, and processes of Relaxed Optics in one system. But experimental methods of observation of proper processes and phenomena are various.

Table3. *Basic types of possible phenomena, which is based on the expansion in series of* $\mathrm{Im}(\varepsilon_{ij} \times \mu_{ij})$.

Type of phenomena	Nonradiative processes		
	$\sim E_i...E_j$	$\sim H_i...H_j$	$\sim E_i...H_j$
First order processes (term with sign "+" in (2))	Electrooptical induced processes of phase transformations in irradiated materials	Magnetooptical induced processes of phase transformations in irradiated materials	Mixing electro and magnetooptical induced processes of phase transformations in irradiated materials
Second order processes (term with sign "–" in (2))	Electrooptical reradiative induced processes of phase transformations in irradiated materials	Magnetooptical reradiative induced processes of phase transformations in irradiated materials	Mixing electro and magnetooptical reradiative induced processes of phase transformations in irradiated materials
Multy (N) order processes	Electrooptical N-reradiative induced processes of phase transformations in irradiated materials	Magnetooptical N-reradiative processes of phase transformations in irradiated materials	Mixing electro and magnetooptical N-reradiative induced processes of phase transformations in irradiated materials

The classifications of Tables 2 and 3, which are based on expansion in series $\varepsilon_{ij} \times \mu_{ij}$, allows determining the basic peculiarities of proper processes and phenomena. But expansion in series $\varepsilon_{ij} \times \mu_{ij}$ wasn't use in modern physics. Thereby methods of parametrical (crystal) optics may be generalized and expanded on RO [2].

3. Experimental Data and Its Discussions

Some peculiarities of Relaxed optical phenomena may be analyzed with profiles of laser-induced subsurface donor centers in InSb and InAs (Fig.1 and Fig.2) [1, 2, 11].

The profiles of the distribution the photostimulated donor centers in subsurface layers InSb and InAs are represented in Fig. 1 [1, 2]. The samples of p-type conductivity are irradiated by pulses of Ruby laser (wavelength $\lambda = 0,69$ µm, duration of pulse τ_i = 20 ns). For intensity of irradiation I_0>0,001 J.cm^{-2} for InSb and I_0>0,0012 J.cm^{-2} for InAs the n-layers on p-type materials are created. For intensity of irradiation I_0<0,1 J.cm^{-2} for InSb and I_0<0,16 J.cm^{-2} for In As the profiles of the distribution of donor centers are represented the Buger-Lambert law (law of absorption the light in homogeneous media). For further increasing the irradiated intensity the profiles of the concentration donor centers have diffusion nature. The visible destruction of the irradiated semiconductor (melting, the change of the surface colour) had place for I_0>0,3 J.cm^{-2} for InSb and I_0>0,5 J.cm^{-2} for InAs.

For explanation of results of Fig.1 modified model of photoeffect for irreversible case was created. Curves 1, 2 and 4 are corresponded to kinetic approximation of this model (kinetic phenomena of Table 1) [1], curves 3, 5, 6 are corresponded to dynamic approximation of this model (dynamic phenomena of Table 1) [1]. Microscopic mechanisms of these results was observed with help model of cascade step-by-step excitation of proper numbers and types of chemical bonds in the regime of saturation the excitation [1,2,12]. For indium antimonide two-dimensional lattice of sphalerite was used [12], for silicon – phase diagram [13]. According to this model, curves 1, 2, 4 of Fig. 1 are corresponded to breakage two from three chemical bonds [12]. This case is corresponded of two-photonic absorption and may be represented as irreversible generation of second harmonic, classic optical observation of second harmonic for self-absorption is impossible [7].

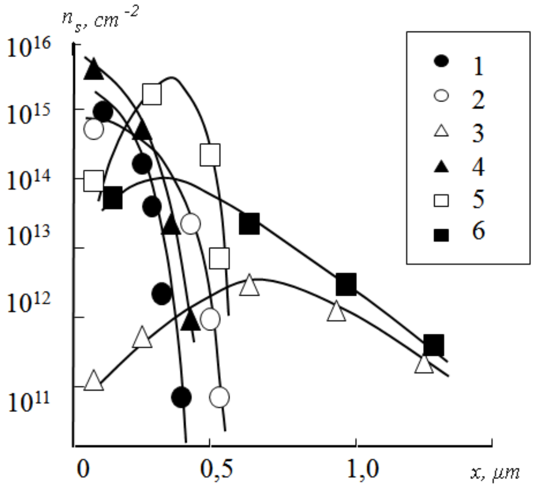

Fig1. *The profiles of the distribution the layer concentration of the donor centers in inverse layers InSb and InAs after Ruby laser irradiation with various density of energy (monoimpulse regime): 0,07 (1); 0,1 (2); 0,16 (3); 0,16 (4); 0,25 (5); 0,5 J·cm^{-2} (6). 1-3 – InSb, 4-6 – InAs.*

The dependence of the creation donor centers in subsurface layers of InSb after Nd:YAG and Ruby laser irradiation is represented in Fig.2 [11]. The profiles of a distribution of donor centers in *InSb* after laser irradiation were researched by V. Bogatyryov and G.Kachurin [11]. An irradiation was created with help Ruby laser ($\lambda = 0,69$ μm, τ_i = 5 – 6 ms) and series of pulses Nd:YAG-laser (λ = 1,06 μm, τ_i = 10ns, frequency of repetition of pulses was 12,5 Hz). A value of threshold the energy of creation n-layers is equaled ~5 J.cm^{-2}. A tendency of the saturation the layer concentration had place for the energy density ~30 J.cm^{-2}. The melting of surface has place for this value of the irradiation.

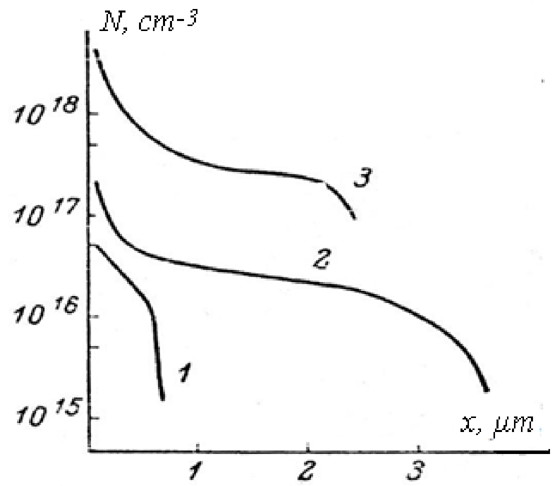

Fig2. *Profiles of the volume distribution electrons after laser irradiation. 1, 2 – Ruby laser; 3 – YAG:Nd laser. Energy density in pulse, J□cm^{-2}: 1 – 5; 2 – 40 [11].*

Form of curves 2 and 3 of Fig. 2 showing an influence two multiphotonic processes on formation of resulting profile of distribution of donor centers. Subsurface region (~0,5 μm) is corresponded to two-photonic self-absorption as for curves 1, 2 and 4 of Fig. 1. Middle parts of curves 2 and 3 of Fig. 2 are corresponded of multiphotonic absorption with photon energy 0,18 eV (band gap of InSb). Basic processes for this case are processes of photon fracturing and further reirradiation of bulk semiconductor [1,2]. Number of reradiations may be 400-500 [1, 2]. Therefore "quantum yield" of creation donor centers for millisecond regime of irradiation is substantially smaller as for nanosecond regime.

One of important problems of RO is laser-induced formation of nanostructures [1, 2]. In first time laser-induced interferograms vere received after Ruby laser irradiation of Ge (Fig.3) by M.Birnbaum in 1965 [14].

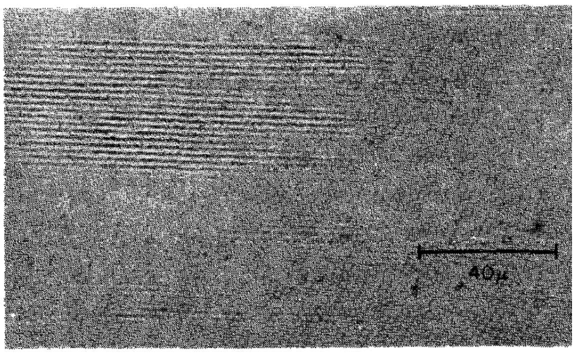

Fig3. *Photomicrograph of Ruby laser induced surface damage of {100} face of a germanium sample [14].*

Later these results were developed to interference laser annealing of semiconductors [15]. But this fact is corresponded to the structural changes of laser-irradiated pure media and media with impurity and damages. Impurities and damages in the irradiated material have little influence on the formation of the interferogramms [2]. Nanostructures formed by crest of interferograms. Its formation is depended from parameters of irradiation. Therefore these phenomena have more deep nature as laser annealing of ion-implanted materials [1,2,15].

Medvids researches [3] shown that these interferograms have nonostructural nature (nanohills). AFM 3D image of GaAs surface after irradiation serie of pulses by YAG:Nd laser (density of power I=5.5 MW·cm^{-2}, λ = 0,532 μm, τ_i = 10 ns) is represented on Fig.3 [3]. Nanohills have various high and place in the maximums of interferograms.

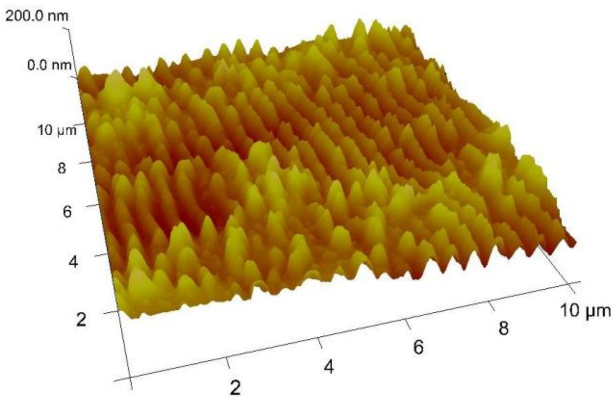

Fig4. *AFM 3D image of GaAs surface after irradiation by second harmonic Nd:YAG laser at I=5.5 MW·cm^{-2} [3].*

Laser-induced silicon nanostructures (λ = 0,8 μm, τ_i = 100 fs, number of pulses 200) with d_3=90 nm, which was generated after irradiation structures of changing polarization with d_2=120 nm, when orientation of vector $\vec{E}$ was changed on 90° relatively to initial action. Power of laser irradiation was less in two time as for initial structure. Generated periodical structures (Fig.5 and 6) are nanocolumns with height to 400 nm with spatial period 90 nm and orientation wave vector $\vec{g} \parallel \vec{E}$ [4]. Where ğ is beam propagation direction.

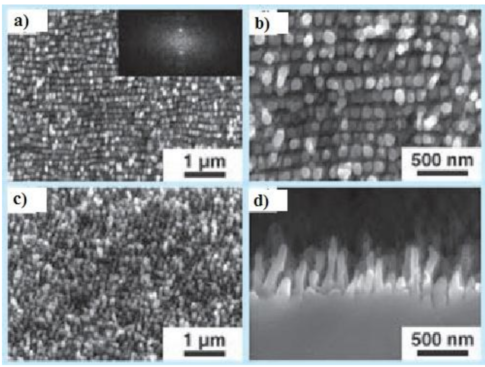

Fig5. *Nanocolumns, which are generated after irradiation structures of silicon with d_2=120 nm, (wavelength of irradiation 800 nm, number of pulses – 200, density of energy of irradiation 0,5 kJ/m^2): a) and b) turn of polarization on 90°, c) turn of polarization on 45°, d) cross chip of nanocolumns. On insertion to Fig. 4a – Fourier-picture of structures [4].*

Generation of periodical nanostructures along crests (d=90 nm) is cause with interference of falling radiation with surface polariton, which are exited along crest of relief (d~120 *nm*), and with mutual interference of surface polariton-plasmon. A crest of relief, which considered in contact with the substrate, was selected as initial half-cylinder. Formed in this case inoculating regular relief d~90 nm is basis for further growth of nanocolumns. Since typical radius of half-cylinder $r << \lambda$, therefore dispersion relation for surface polariton-plasmon in cylindrical geometry is changed from dispersion relation in plane geometry of phase separation. It cause to formation nanostructures with less period as for plane case [4].

For case of elliptic polarization and falling angle to surface from 0° to 20° basic nanostructures are created: 1) surface nanostructures with period ~200 *nm* and 2) these structure with period 70–100 *nm* are generated on crest of structure 1, but its orientation $\vec{g} \perp \vec{E}$ [2,4].

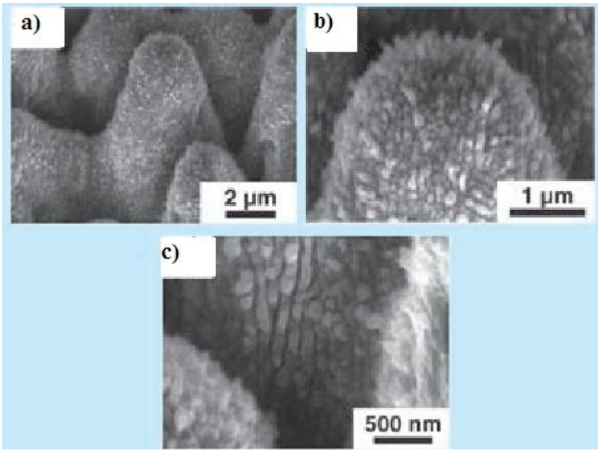

Fig6. *Surface silicon nanocolumns of little scale, which have orthogonal orientation to a crests of nanorelief of large scale [4].*

Basic difference between nanosecond (Fig. 4) and femtosecond regimes of creation of surface nanostructures (Fig. 5 and Fig. 6) is the its sizes: 15-20 nm for nanosecond regime of irradiation (nanohills) and 400-450 nm for femtosecond regime of irradiation (nanorods or nanocolumns). These data are proved electromagnetic mechanisms of creation surface nanostructures (surplus of negative charge is caused the electromagnetic swelling of surface) [2]. Heat processes are caused the decrease of sizes, including height of surface nanostructures.

For the modeling processes of Fig.5 we must develop concept of Table 3. This concept allows including in parametric optical processes back side of “medal”: resulting trace of interaction light and matter in matter [1].

Roughly speaking, basic causes of laser-induced generation of interferograms and nanohills are creation of surplus of negative charge and, as result, plasmonic oscillations in subsurface region. Surplus of negative charge is caused symmetry and stehiometry of each nanohill or nanocolumn.

For case of binary semiconductors surface and peak of nanohill are rich of acceptor component. Symmetry of each nanohill is decreased from basis to peak. For silicon it may be next chain: structure with coordination number CN=8, structure with CN=6, structure with CN=5, structure with CN=3 and proper quasicrystal modifications. But this scenario is characterized plasma regime of irradiation, when processes of melting, evaporation and sublimation are negligible. Including thermal characteristics are caused the decreasing and spreading of nanohills. Hear chemical and structural characteristics may be changed too.

As example of "irreversible" Cherenkov effect may be represented picture of Fig. 6. Angle θ is corresponded to angle of Cherenkov radiation [16].

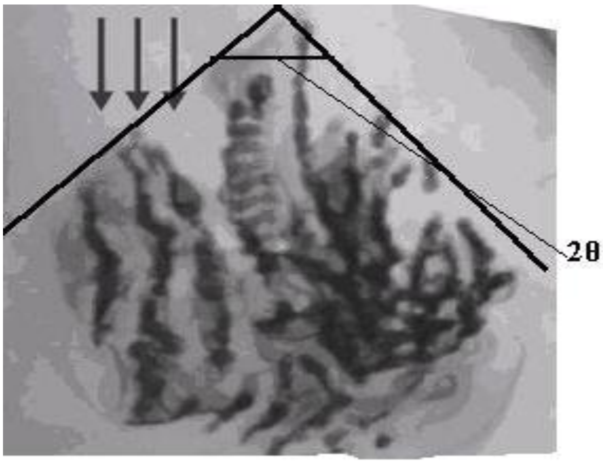

Fig6. *Bright field TEM image of the cross section of a line written with pulse energy of 300 nJ/pulse [1, 2, 16].*

Process of self-focusing may be represented as macroscopic analogous of process of deceleration of charge particle in matter [16]. N. and A. Bohr created microscopic theory of Cherenkov radiation on the basis last process [17-19]. The creation of bulk destruction of irradiated matter may be explain with help Lugovoy-Prokhorov theory of moving focuses [6] and nonlinear optical processes at streamer discharge in semiconductors [5].

Mechanisms of creation surface nanostructures and volume destruction of irradiated matter have simple nature, but for the creation surface nanostructures we must have energy in two time less as for volume processes [1, 2].

4. Some Applications

Relaxed optical processes may be used for the creation new structures from optoelectronics to arts [1].

The problem of the creations stable structures is one of the central in modern optoelectronics. The semiconductors $InSb$ and $InAs$ is one of the basic for the creation infrared photo detectors in spectral range 3 – 5 μ ($1\mu = 10^{-6}\,m$). The p–n junctions may be received with the help of Relaxed Optics (RO). These junctions have more abrupt border between donor and acceptor layers than another. The irradiated layers have more high concentration of stable donor centers and little thin.

The receiving the n-layers on $p-InSb$ and $p-InAs$ after irradiation the impulse Ruby laser [1,2] allow have these devices. But best p–n junctions were be receiving with help mixed ion-laser irradiation (ion implantation and CO_2–laser irradiation). Last structures have best characteristics than first. The problems of the creation various p-n junctions and its theoretical discussion are represented too.

The influence of spectral ranges of laser irradiation on the creation the irreversible changes in $InSb$ and $InAs$ is represented in [2]. Next types of the irradiation were used. Impulse ruby Ruby laser regime had next parameters: duration of impulse $\tau_i = 2\cdot 10^{-8} s$; energy of the photon $h\nu = 1{,}8\,eV$; density of energy flow $I_0 = 0{,}001 - 0{,}3\ J/cm^2$. Impulse CO_2–laser – $\tau_i = 10^{-6} s$;

$h\nu = 0{,}117\ eV$; $I_0 = 0{,}1 - 15\ J/cm^2$. And stationary CO_2–laser – $\tau_i = 10^{-3} - 10\,s$; $h\nu = 0{,}117\ eV$; density of power $W_0 = 10 - 30\ W/cm^2$.

The renewal structure and full activation of the impurity in Mg^+–implanted layers $InSb$ (ion energy 100 *keV,* dose $6{\cdot}10^{14}\ cm^{-2}$) is possible only for the CO_2–laser irradiation with density of energy flow $I_0 = 10\ J/cm^2$ [2, 20]. Analogous process renewal structure and full activation of the impurity in S^+–implanted layers $InAs$ (ion energy 40 *keV,* dose $10^{14}\ cm^{-2}$) is possible for the CO_2–laser irradiation with density of energy flow $I_0 = 12\ J/cm^2$ [21].

This effect is integral and isn't depended from the regime of irradiation (impulse or stationary) for regime of CO_2–laser irradiation.

The renewal of structure is happen after impulse Ruby irradiation with $I_0 = 0{,}16\ J/cm^2$ for indium antimonite in measurement Rutherford backscattering spectra ion H^+ with energy 500 keV and He^+ with energy 1, 8 MeV. But activation of the impurity isn't happen [1, 2, 20].

But the creation of new donor centers in $InSb$, $InAs$ and Si after impulse laser irradiation with $h\nu > E_g$ allow to receive $n-p$ junctions. n–layers were stable for the $I_0 = 0{,}1\ J/cm^2$ for $InSb$ and $I_0 = 0{,}16\ J/cm^2$ for $InAs$. Proper Volt–Ampere characteristics are curve 2 ($InSb$) and curve 3 ($InAs$) on Fig.7 [1, 20]. These characteristics have more "bad" character as characteristics of curve 1.

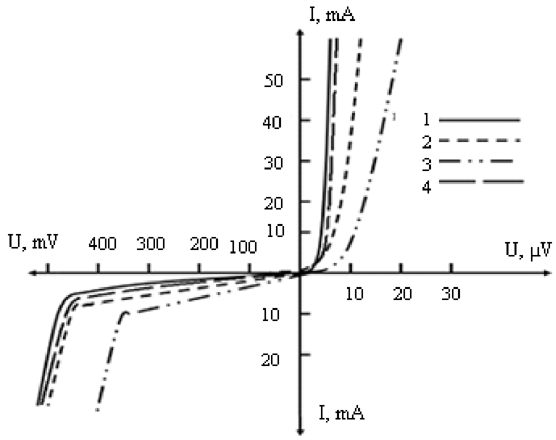

Fig7. *Volt-Ampere characteristics p-n and n-p junctions: LAIIL, curve 1 – Mg^+/InSb [1, 20], curve 4 – S^+/InAs [21]; LIDL, curve 2 – InSb[1,20], curve 3 – InAs [1,20].*

This difference may be explained in the following way. The CO_2–laser annealed ion–implanted layers (LAIIL) are the more stable centers as Ruby laser induced donor layers (LIDL). The depth of LAIIL is 0, 2–0,4 μ, the depth of LIDL – 0,6–6 μ. The edge of ion–implanted layer is more abrupt as laser–induced layers. It is basic causes of the best electrophysical properties LAIIL as LIDL.

The difference between physical properties of the LAIIL and LIDL supplement the explanation of the conclusion about impossibility of the laser annealing ion–implanted layers with irradiation in regime $h\nu > E_g$, where E_g – band gap of semiconductor [2]. The index of absorption in pure $p-InSb$ of the CO_2–laser irradiation is $10\ cm^{-1}$, Ruby laser – $2\cdot 10^5\ cm^{-1}$. The index of absorption in $Mg^+/InSb$ layers of the CO_2–laser irradiation is $10^4\ cm^{-1}$. Therefore in the first regime (curve 1, Fig.7) of the irradiation we have one process – light scattering on metastable centers and this effect isn't depended from the time of the irradiation. The heat effects (for impulse regime of the irradiation) have the same direction as photoinduced phenomena.

The proper concentration profiles of distribution of donor centers for "stable" regimes of the irradiation for $InSb$ and $InAs$ are represented in Fig.1.

The difference of absorption indexes for Ruby and CO_2–laser irradiation is caused of the impossibility of laser annealing and activation implanted impurity with the help of the laser irradiation with regimes $h\nu > E_g$. For the laser annealing of ion-implanted layers must be used the irradiation with $h\nu < E_g$. The irradiation with $h\nu > E_g$ is the processes of light scattering on stable centers (covalent bonds for $InSb$ and $InAs$ [1]). This process is caused of the generation high concentration of donor centers. Defects of ion implantation have n type of the conductivity too. The thermal defects in $InSb$ have p –type of conductivity [1]. Therefore the contradiction in the explanation of the cause the creation and annealing damages and activation impurity in $InSb$ is founded on various charge states laser induced damages and thermal defects.

5. Some Problems of Development

Basic problems of RO may be classified in next way [22]: 1) experimental problems; 2) theoretical problems; 3) problems of application.

Experimental problems are next: generation of proper phase transformations (surface, subsurface and volume) in irradiated materials; homogeneity of irradiation and reproduction of characteristics of irradiated materials.

Phase transformations in irradiated materials are depended from characteristics of radiation (time, wavelength and intensity) and properties of irradiated matter (stable, metastable or unstable center of light scattering). Other words we must include mechanisms of light scattering and here influence on the phase transformations in irradiated materials. Multyphotonic and lasing processes have influence on the formation of irreversible changes in irradiated materials. Problems of laser annealing of ion-implanted or other "damages" materials was resolved with including of mechanisms of light scattering (impurity or damages absorption). Redistribution of impurity in irradiated matter is depended from here charge and intensity of irradiation. These researches must be united with researches of structural changes in irradiated materials. So, nanocolumns, which is created with help femtosecond laser irradiation in silicon, may be have four crystal and eight quasicrystal modifications [1-3]. The structures with more small coordination numbers have various number of bound electrons and various electro negativity. Therefore donor and acceptor impurities will be have various physical and transport properties, including solvability. For example, crystal structures of silicon after femtosecond laser irradiation may be change from diamond (beginning structure, basis of nanocolumn) to trigonal symmetry (peak of nanocolumn). Electromagnetic swelling of surface for under evaporating regime of irradiation is caused the increasing a concentration of negative ions in higher surface layers and the increasing a concentration of positive ions in more deep surface layers. This picture may be changed for regime of surface evaporation [1, 2].

Very interesting results may be received after irradiation transparent structures in the regimes of self-focusing and self-trapping. In the last regime we can receive dynamical or irreversible homogeneous volume periodical structure.

Basic theoretical problems of RO are the search of way of modeling, controlling and prognostication basic here phenomena and processes. These modeling must be including methods of electrodynamics, plasma physics and physical chemistry. Significant difference relaxed and nonlinear optical processes may be represented in next way. Nonlinear optical processes, including lasing, are the processes of excitation of system of free or weak-interacted harmonic oscillators. Therefore methods of classical and quantum electrodynamics are used for the modeling of these processes and phenomena. Relaxed optical processes can't be represented with help of system harmonic oscillator because here are caused of phase transformations of irradiated matter. In this case we can use methods of physical chemistry: cascade excitation in the regime of saturation step-by-step of proper chemical bonds. For modeling of second order processes of RO plasmic and thermal methods may be using effectively. Elements of catastrophe theory, synergetics, Feygenbaun dynamics and other methods of nonlinear dynamics may be used too.

Basic applications of RO processes and phenomena are next: laser annealing of ion-implanted materials (annealing of radiation damages and activation of impurity); laser implanted of matter (change of physical properties of laser-irradiated compounds); laser-induced generation of surface and bulk nanostructures (nanocones, nanohills and nanocolums); creation of laser-induced volume periodical structures. For example, surface nanostructures may be used as diffraction grating with variable period and as object for the research of quantum interference and diffraction. In addition methods of RO may be used for the generation of allotropic phase of carbon and other simple processes.

6. Conclusions

- Basic concepts of RO (phenomenological chronological-energy classification of phenomena of irreversible interaction light and matter and classification on basis of expansion in series Pointing tensor) are analyzed.
- Problems of creation laser-induced donor centers in InSb and InAs are represented and discussed.
- Processes of generation of surface interferograms and nanostructures are analyzed.
- Phenomena of creation of laser-induced volume destruction of matter are discussed too.
- Some problems of applications relaxed optical processes on the examples InSb and InAs are discussed.
- Problems of development theoretical, experimental and applied aspects of RO are analyzed too.

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