THE HEAT TRANSFERRING IN THE PULSE IRRADIATED CRYSTALS WITH NON-LINEAR HEAT PARAMETERS

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Summary: The processes of heat transfer in the pulse irradiated crystal with non-linear heat parameters was studied. The implicit numerical method applied. It has been showen, that the non-linearity of heat parameters essentially changes conditions of heating and cooling to a crystal. Time evolution of heat field in depth of crystals in different condition of pulse irradiation was investigated.

INTRODUCTION

The fast development of technologies with application of materials or the nanodimentional frames in optoelectronics stimulates to investigate their properties heat and mass transferring. In particular analysis of heat transferring is necessary at mining lasers on the basis of semiconductor structures with quantum embedding. Insufficient heat transferring from of a solid active element results to over heating of a working section and according to a low overall performance of the laser [5].

In numbers of papers [3, 4] the temperature dependencies of thermal conductivity in nanostructures were determined, for a pore which one was have been entered the conforming active chemical elements and connections, which one create unilateral injection of charge carriers and accordingly change heat rejection. On the basis of these temperature dependencies of thermal conductivity was a put there have been a problem to investigate processes of the heat transferring irradiation by a laser and electronic beam to a crystal.

MATHEMATICAL DESCRIBING AND NUMERICAL CALCULATION

We investigated an one unidimensional measurable case of heat transferring process in crystal conditions when heat transfer is non-linear. For this aim the non-linear non-stationar differential equation of heat transferring process was solved by implicit three point method [1, 2]:

$$c\rho\frac{\partial T}{\partial x}=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+f, \qquad (1)$$

where c – heat capacity, ρ - crystal density, k(T) – thermal conductivity [W/(m K)], T=T(x, t) - temperature, f-power density of heat sources, that is quantity heat, that is excreted per unit length in unit of time, f=p (x, t)-Q, where Q-secretion of heat into exterior environment, p (x, t) - density heat power, which one is excreted at absorption of a laser and electronic sources.

Boundary conditions for heat flow on the crystal surface where given in the form of the II range conditions, which take into consideration a convective heat flow, heat radiation flow and was represented by following equations:

$$\frac{\partial T}{\partial x}\Big|_{x=0} = 0 \qquad ; \frac{\partial T}{\partial x}\Big|_{x=d} = 0 \qquad (2)$$

Temperature dependence of coefficient reflection of radiation for silicon is approximated by expression:

$$1-\alpha(T) = 0{,}322 + 3{,}17\cdot 10^{-5}T \qquad (3)$$

Heat-transfer was described by empirical expressions:

$$k(T) = \frac{1521}{T^{1{,}226}} \qquad (300K<T<1200K) \qquad (4)$$

$$k(T) = \frac{8{,}87}{T^{0{,}502}} \qquad (1200K<T<1683K) \qquad (5)$$

Sample heat capacity temperature relation was represented by following expression:

$$c(T) = \frac{0{,}0742}{300}T + 0{,}641 \qquad (T>300K) \qquad (6)$$

Temperature distributions and their time evolution on the surface and to crystal depth under pulse treatment we have calculated by the implicit numerical method.

In the case of initial and boundary conditions which are satisfacted to lack of energy loss connecting with convection and reradiation into exterior environment equation (1) will gain the look of equations system:

$$\alpha T_{i,k+1} + \beta T_{i,k} + \gamma T_{i,k-1} - f = 0 \qquad (7),$$

where i,k – indecies of time and coordinates evolutions:

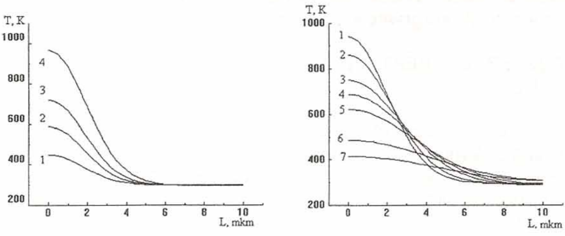
$$\alpha = \frac{\tau k}{c\rho}, \beta = -\frac{\tau k}{c\rho + h^2}; \gamma = \frac{\tau k}{c\rho}; f = \frac{\tau k}{c\rho P(x,t)} - T_{i-1,k}h^2 \qquad (8).$$

System (7) was solved by matrix dispelling.

Heating executed by a laser and electronic beam, for which one there are properties of heat absorption on depth of irradiated sample. For laser heating of the heat absorption is described by exponential law $p=p_0\exp(-\alpha x)$, where x - coordinate to the depth of sample, p_0- power of irradiation on a surface to a crystal, α - absorbtion coefficient of radiation. For electronic heating of absorption is implemented under the law $p=p_0\exp(-(x-d)^2/1.44r))$, where d is depth infiltration of electrons into a material (depth Widdington-Tompson), r- width gaussian curves, where the electrons greatest are dispersed.

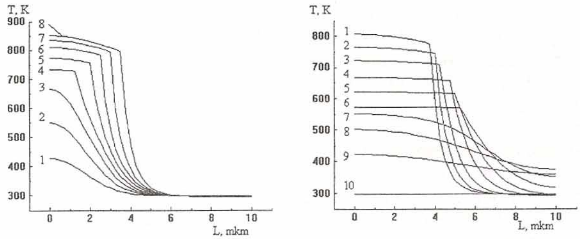
ITRANSFER OF HEAT IN A SOLID STATE AT PULSE LASER HEATING

In figures the evolution of the temperature profiles in the period from a beginning to termination of a laser and electronic pulse (figures a)) are represented. The curves in figures b) describe the change of coordinate distributions of temperature on depth to a crystal after termination of pulse influence. Last curve in figures b) responds a temperature balance with environment.
Substantially in crystals the heat parameters essentially change with temperature. We have considered a number of modeling with temperature dependencies of thermal conductivity.
Constant and step-like thermal conductivity coefficients.
Family of curves of features 1a is obtained for power p_0=0.002 W/μm^2 at the constant heat conduction at all temperatures ($\kappa=10^{-7}$ W/(m K)). The heating and cooling curves figure 1a and 1b have monotonically nature, descending from coordinate, gaining extreme values of temperature on a surface of a sample at the moment of termination operating of a momentum pulse (T > 1000 K).
The nature of temperature fields distribution in the crystal essentially changes at of a dependent heat conduction function on temperature. In particular at step-like increase of heat conduction at the definite temperature (T=600 K) the nature of described temperature field evolution as presented on fig. 2, 3, 4.
At achievement of temperature T=600 K for $\kappa=10^{-7}$ from 300 up to 600 K (fig. 2a, 1-3)) the heating implements under the scheme represented on fig.1a (1-3). At the temperatures higher the T=600 K and $\kappa=10^{-5}$ and on the surface crystal the heat becomes more quickly to be diffused into the depth and consequently on a back side of a sample the temperature decay to a heavy gradient. At the moment of the termination of pulse the decay of temperature and general cooling of a sample starts. Simultaneously there is fast heat transfer to a back part of a crystal (fig. 2b, 1-6). Cooling lowest T=600 K (7-10) is likely under the scheme of figure 2b (5-7). Except for change of nature of distribution of temperatures lowest temperature of maximum heating of a surface (850 K), despite of 1,5 times increase of power (p_0=0.003) was observed, that is connected to fast transferring of heat to the depth to crystal (4-8, fig. 2a).
At $\kappa=10^{-5}$ and T<500 K descends a fast heating on all sample (1-4, fig. 3a). At T>500 K and $\kappa=10^{-7}$ the sharp decreasing of heat conduction results in decreasing heat transferring to the depth and strong heating of near interface areas (5-6), profiles by which one similar to 3-4 (fig. 1a) in a near interface layer. The cooling is symmetrical to heating.



a) b)

Fig. 1. Profiles of heating (a) and cooling (b) to a crystal under operating of a pulse laser exposure at constant thermal conductivity $\kappa=10^{-7}$

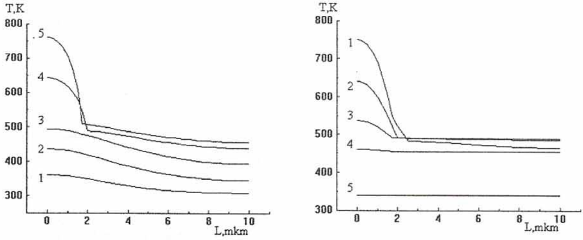


a) b)

Fig. 2. Profiles of heating (a) and cooling (b) to a crystal under operating of a pulse laser exposure at step-like thermal conductivity: $\kappa=10^{-7}$ at the temperature of T<600 K and $\kappa=10^{-5}$ at T>600 K

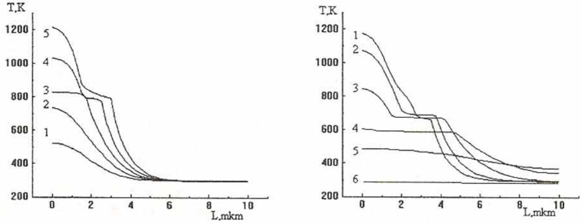
П-like thermal conductivity.

The change profiles of П-like temperature dependence of heat conduction was esteemed also. At operating a pulse, and after termination heating and the cooling are by the sum of two precursor profiles. The curves 1-6 (fig. 4a) respond profiles 1-6 fig. 2a in temperature range 300-800 K. At higher temperatures from 800 K curves 7 fig. 4a and 1-2 fig. 4b respond profiles of a fig. 3a and 3b respectivily. The cooling curve 3 (fig. 4b) is combining of two precursor cases in temperature range 600-800 K. At the lowest temperatures 600 K cooling is likely under the scheme of fig 2b was at 950 K, that is higher as against two precursor cases. This heating of a surface is connected with that in temperature range 600-800 K heat conduction such same as in case of 2, that has resulted in heating up to 800 K, after which one there is a slump of heat conduction, that has resulted only to the heating of a near interface areas, instead of fast distribution of heat to the crystal depth .



a) b)

Fig. 3. Profiles of heating (a) and cooling (b) to a crystal under operating of a pulse laser exposure at step-like thermal conductivity: $\kappa=10^{-5}$ at the temperature of T>500 K and $\kappa=10^{-7}$ at T<500 K

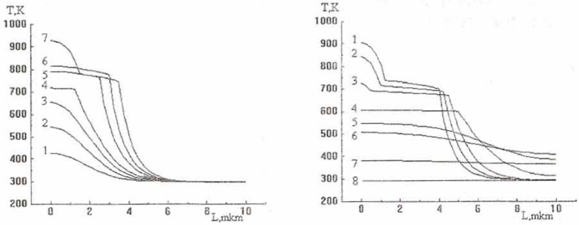


a) b)

Fig. 4. Profiles of heating (a) and cooling (b) to a crystal under operating of a pulse laser exposure at Π-like thermal conductivity: $\kappa=10^{-5}$ for a temperature band [600; 800] and $\kappa=10^{-7}$ for all other temperatures

Gaussian-like thermal conductivity.

In case of 5 Π-like model of heat conduction is exchanged on gaussian-like relation with center 700 K by width 60 K. Of essential changes in temperature profiles was not held as against a precursor case. However, the heating of a near interface layer (up to 2 microns) up to 1200 K was increased, that is connected to width gaussian curves (that is it is area of temperatures where the thermal conductivity is by greatest), which at increasing up to 200 K will show a precursor case with Π-like dependence of a thermal conductivity function .



a) b)

Fig. 5. Profiles of heating (a) and cooling (b) to a crystal under operating of a pulse laser exposure at thermal conductivity $\kappa=10^{-5}\exp(-(T-700)^2/4000))$ for a temperature band [600; 800] and $\kappa=10^{-7}$ for all other temperatures

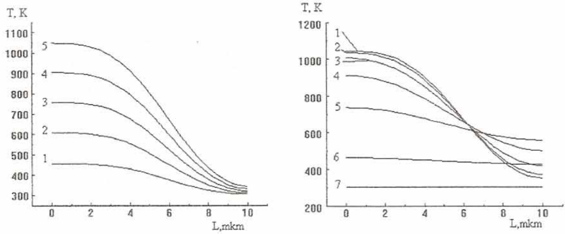
TRANSFER OF HEATING A SOLID STATE UNDER HEATING BY PULSE ELECTRON BEAM

In figures 1.1, 2.1, 3.1, 4.1, 5.1 are presented the temperature profiles of heating and cooling under operating by a electron beam of the same duration, power and temperature dependent heat conduction, which are the same as for laser heating.

The characteristic feature for all profiles of heating from a electron beam is increase of maximum heating temperature on the crystal interface, more speed heat transfer of a sample depth as against laser processing. It is connected that the power of electrons is excreted in a crystal for gaussian dependence on definite depth d. The sample sooner heats than large width gausian curves r, that is where the electrons greatest are dispersed. The cooling passes already behind known temperature profiles, which one similar to cooling curves at laser heating.

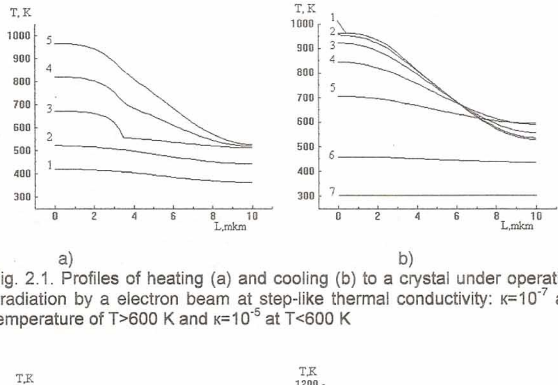
Constant and step-like thermal conductivity.

The new temperature dependence 3 fig. 2.1a was exhibited, where the surface layer (3 microns) has heated over 600 K, as heat conduction at 500 K was increased, and approximately 3 microns of a profile 2 fig. 2.1a were heated up to 500 K.



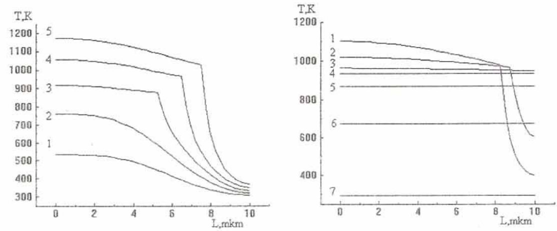
a) b)

Fig. 1.1. Profiles of heating (a) and cooling (b) to a crystal under operating of irradiation by a electron beam at constant thermal conductivity $\kappa=10^{-7}$



a) b)

Fig. 2.1. Profiles of heating (a) and cooling (b) to a crystal under operating of irradiation by a electron beam at step-like thermal conductivity: $\kappa=10^{-7}$ at the temperature of T>600 K and $\kappa=10^{-5}$ at T<600 K

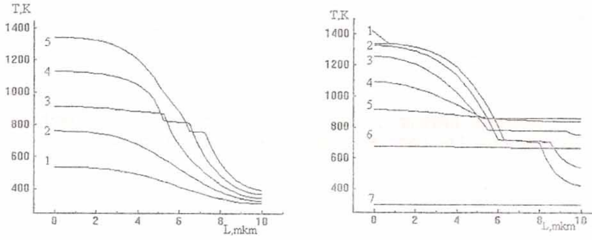


a) b)

Fig. 3.1. Profiles of heating (a) and cooling (b) to a crystal under operating of irradiation by a electron beam at step-like thermal conductivity: $\kappa=10^{-5}$ at the temperature of T>500 K and $\kappa=10^{-7}$ at T<500 K

П-like thermal conductivity.

Steps by a curve of a fig. 4.1a respond temperature band [700; 900], which one are connected to fast distribution of heat for a depth of a material at temperatures from 600 up to 800 To. Further operating of a pulse results only to raising of temperature on a surface to a crystal. The temperature dependence 3 is as a matter of fact sum of curves 3 fig. 2.1a and fig. 3.1a.

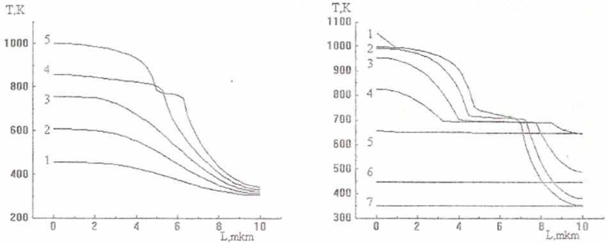


a) b)

Fig. 4.1. Profiles of heating (a) and cooling (b) to a crystal under operating of irradiation by a electron beam at П-like thermal conductivity: $\kappa=10^{-5}$ for a temperature band [600; 800] and $\kappa=10^{-7}$ for all other temperatures

Gaussian-like thermal conductivity.

At gaussian-like dependence of heat conduction (fig. 5.1a) has resulted smoothing steps as against 3 fig. 4.1a and the effect is observed only in temperature range [600; 800], where there is a maximum heat conduction.



a) b)

Fig. 5.1. Profiles of heating (a) and cooling (b) to a crystal under operating of irradiation by a electron beam at thermal conductivity $\kappa=10^{-5}\exp(-(T-700)^2/4000))$ for a temperature band [600; 800] and $\kappa=10^{-7}$ for all other temperatures

CONCLUSION

The processes of heat transferring at model dependence coefficient of heat conduction from temperature were are conducted for visual observation of heating rate and cooling of crystals. In lasers on the basis of solid semiconductor structures with quantum embedding of an active elements at a recombination of injection carriers there is a heating to a crystal, which one negatively influences activity of the laser. From these modeling it is possible to pick up optimum thermal conductivities, which one then could apply to fabricating of active elements, which one will render assistance a reliable operation of solid lasers on the basis of semiconductors with quantum embedding.

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