

PHYSICAL AND MATHEMATICAL SCIENCES

MODELING OF TEMPERATURE DISTRIBUTION IN THE STRUCTURE A-SI-SN-A-SI AT LASER IRRADIATION

Oleksandr Havryliuk¹

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The film composite «Si nanocrystals in the matrix of amorphous Si» (nc-Si) is considered a promising material for the next generation of solar cells (CE) at quantum dots [1, p. 951]. Among the main problems that inhibit the practical implementation of the advantages of nc-Si is the insufficient development of technologies for controlling the size and concentration of Si nanocrystals at economically justified film formation rates. The distribution of temperature profiles, which arises during laser irradiation, plays an important role in the formation of nanocrystals in the a-Si-Sn system. Therefore, the aim of this work is to determine the temperature and time parameters of metal-induced crystallization (MIC) in such a system, as well as the prospects of using pulsed laser radiation to regulate the size and concentration of nanocrystals in tin-induced crystallization of amorphous silicon.

When describing the process of laser heating of a substance, two circumstances are significant. First, due to the penetration of light into the environment, optical heat sources should be volumetric, is distributed in the volume of the medium, and not localized, for example, at its boundary, as in the problems of ordinary thermal heating. Second, the release of optical energy is heterogeneous in the amount of interaction due to the decrease in light intensity as it penetrates deep into the environment. The latter circumstance leads to spatially inhomogeneous heating of the substance and determines the processes of heat and mass transfer between different parts of the environment.

The propagation of the temperature field on the surface of a solid body when heated by a laser pulse can be represented as follows [2, p. 714]:

$$\rho c_p \frac{\partial T}{\partial t} - \nabla[k \cdot \nabla T] = \alpha I_0(t)(1 - R) \exp(-\alpha|z|) \quad (1)$$

where I_0 is intensity of laser radiation incident on the surface of a solid body, R is coefficient of light reflection, α is absorption coefficient of laser radiation, T is temperature, Q is amount of heat received per unit volume of

¹ Chuiko Institute of Surface Chemistry NAS of Ukraine, Ukraine

matter, ρ is density of matter, k is thermal conductivity, c_p is heat capacity at constant pressure.

Simulation of temperature change in the mode $\lambda = 1070 \text{ nm}$, $\tau_p = 10 \text{ ns}$

To calculate the temperature distribution in the sample by a nanosecond laser pulse with a duration of $\tau_p = 10 \text{ ns}$ and the irradiation intensity $I = 5\text{-}85 \text{ MW/cm}^2$ in formula (1), we use the time intensity distribution $I_0(t)$ according to Gauss's law:

$$I_0(t) = I_0 \cdot e^{-\frac{4(t-\tau_p)^2}{\tau_p^2}}$$

When irradiated with a laser with a pulse duration of 10 ns, we observe a noticeable difference in temperature distribution in the upper layer of amorphous silicon and tin. First, the tin layer is heated and as a result of the thermal conductivity process, the layers of amorphous silicon are already heated. Moreover, as evidenced by the data in Figure 1 and 2 after 40 ns from the beginning of annealing, the temperature on the surface of the upper layer of amorphous silicon becomes higher than in the tin layer and after 40 ns from the beginning of irradiation the temperature in the tin layer becomes lower than its melting point. With this pulse duration, it can be seen that all the energy received with the laser pulse is mainly used to heat the layers of tin and amorphous silicon, without heating the silicon substrate.

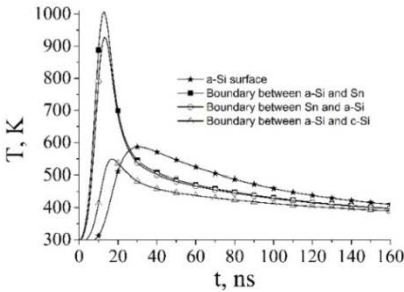


Figure 1. Estimated increase in temperature in different parts of the sample at laser heating ($\tau_p = 10 \text{ ns}$, $\lambda = 1070 \text{ nm}$, $I = 75 \text{ MW/cm}^2$).

Simulation of temperature change in the mode $\lambda = 535 \text{ nm}$, $\tau_p = 10 \text{ ns}$

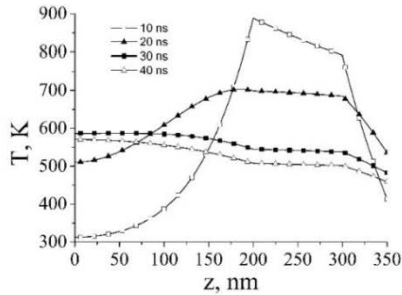


Figure 2. Temperature distribution over the thickness of the sample, not taking into account the silicon substrate, at different times ($\tau_p = 10 \text{ ns}$, $\lambda = 1070 \text{ nm}$, $I = 75 \text{ MW/cm}^2$).

Light with $\lambda = 535$ nm is almost completely absorbed in the outer amorphous silicon (Figure 3), as a result of which the temperature on the surface of the sample is much higher than on the surface of tin. At this wavelength at high intensities, partial or complete destruction of the outer layer of amorphous silicon is possible. As a result of worse heat dissipation conditions, the maximum local heating temperature and, accordingly, the temperature gradient increase. This can cause greater local deformation stresses and correspondingly greater damage to the outer layer a-Si.

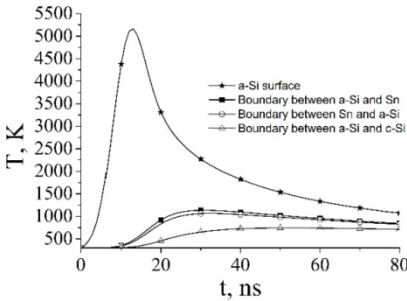


Figure 3. Estimated increase in temperature in different parts of the sample at laser heating
 $(\tau_p = 10$ ns, $\lambda = 535$ nm,
 $I = 75$ MW/cm²)

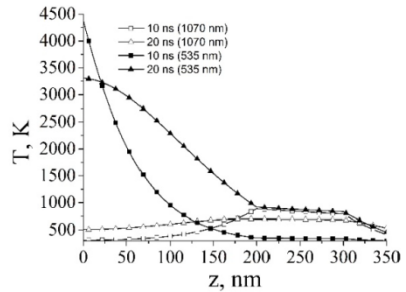


Figure 4. Temperature distribution over the thickness of the sample, not taking into account the silicon substrate, at different times and at different wavelengths
 $(\tau_p = 10$ ns, $\lambda = 535$ nm, $\lambda = 1070$ nm,
 $I = 75$ MW/cm²)

In Figure 4 presents a comparative graph of the temperature distribution at depth at different time intervals at different wavelengths. This graph shows that at a wavelength of 535 nm and an intensity of 75 MW/cm² is more intense heating of the amorphous silicon surface, although in the tin layer the temperature difference when irradiated with different wavelengths in the period of 20 ns from the annealing is insignificant.

Based on the calculations, you can choose the optimal parameters of laser radiation to obtain nanocrystals of the required size, without destroying the structure itself. The coincidence of the temperature of the beginning of structural-phase changes with the melting point of tin confirms that the presence of a liquid state of tin is a necessary condition for MIC. However, the MIC mechanism itself needs more detailed and comprehensive research. Due to the high speed of tin-induced crystallization of amorphous silicon

($10^{-8} - 10^{-4}$ s), its stimulation by pulsed light irradiation can be the basis for new technologies for controlling the size of nanocrystals in the manufacture of film nc-Si.

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DEVELOPMENT OF MATHEMATICAL LOGIC AS A POWERFUL APPARATUS OF MODERN PHYSICS

Tetiana Obikod¹

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The history of logic is rich and contradictory. However, one cannot fail to see the benefits of its development for science as a whole, which gave rise to a new, first formal, and then mathematical logic. The latter had such a strong influence on the development of modern mathematics and physics that we cannot ignore this topic. The history of the development of logic is usually associated with Greece. In spite of the fact, that no one mathematical work on the rules of reasoning has reached us, however, even then the axioms / Archimedes / began to be used. Plato said that «those who study geometry and arithmetic... act in order to arrive at what they had in mind to consider by common agreement» [1]. The transition to axioms seemed to the Greek mathematicians a solid foundation of science [2]. Euclid's «Beginnings» (III century BC) became an example of mathematical theory, an integral axiomatic system of mathematics. In the first book of the «Elements» Euclid gives 14 axioms of geometry and arithmetic, then numerous theorems are logically derived from them. Each theorem is deduced either from axioms or from other proved theorems, and according to the laws of Aristotle's logic / IV century BC / the new theorem is also true. The theory of real numbers of Eudoxus, set out by Euclid in the fifth book of the Elements, was used in Europe until the 17th century.

¹ Institute for Nuclear Research NAS of Ukraine, Ukraine