J. Nano- Electron. Phys.
1 (2009) No2, P. 24-28

PACS numbers: 42.50.Wk, 42.25.Bs, 42.62.Cf

FEATURES OF LIGHT PROPAGATION IN INSULATING MATERIALS OF ELECTRONICS UNDER LASER PROCESSING

S.D. Tochilin, S.P. Lushchin, D.S. Tochilin

Zaporizhzhya National Technical University,
64, Zhukovskogo Str., 69063, Zaporizhzhya, Ukraine
E-mail: tochno@zsu.zp.ua

The study of light propagation in insulating materials of electronics is carried out under evaporating mode of laser influence. As a result of experimental data analysis the rate of through hole formation is determined and the temporal features of the absorption coefficient in investigated samples are established.

Keywords: *LASER, PERFORATION, ABSORPTION, RADIATION, FIBERGLASS PLASTIC, THROUGH HOLE.*

(Received 2 February 2009, in final form 14 March 2009)

1. INTRODUCTION

Laser technologies find a wide application during production of the elements of electronics. Using them the resistor tuning is realized, the *p-n* junctions are created, etc.

Last years laser processing replaces mechanical and chemical engineering during production of the electronic boards with high packing density. In this case the precision hole formation in a board material [1] is the main manufacturing operation. Therefore the study of different regimes of laser influence (LI) on materials is of great importance, as well as the physical phenomena their, which are excited by radiation of industrial laser, for control and optimization of laser processing.

Such investigations were carried out in a number of publications, in particular, in [2, 3]. Thus, some regimes of LI on material surface were considered in [2]. In this case the investigation of evaporating mode of LI on a surface was of a great attention. It occurs under action on material of a laser radiation with parameters: $10^8 < P < 10^{10}$ W/cm^2, $\tau \cong 10^{-8}$ sec, where P is the density of pulse power of laser radiation, τ is the pulse duration. The possibility of realization of pure precision cutting and high-quality perforation [2] for different materials is the feature of evaporating mode. But in [2] the peculiarities of light absorption in samples under laser processing were not taking into account during the study of evaporating mode of LI on materials (including non-uniform and dielectric ones).

At the same time it is known, that under laser processing of a material the increase of its absorption coefficient k [4, 5] takes place. Here, the growth initiation of a volume absorption under LI on a sample surface can be conditioned by the action of different mechanisms, such as, the semiconducting, the thermochemical, etc.

That is, for complete description of LI on materials in evaporating mode it is necessary to consider a question connected with absorption change of laser radiation in work materials as well.

The aim of the present work was to investigate the features of light propagation in insulating materials of electronics, namely, in the foil-coated fiberglass plastic SF-1 and the layered plastic REM under evaporating mode of LI subject to absorption change of laser radiation in work materials.

2. THEORETICAL ANALYSIS

To explain the features of light propagation in investigated samples we used a number of theoretical models. They are based on the model of contra-directional flows, which describes the light propagation in mediums [6]. In this case a dispersion medium is characterized by the absorption coefficient k and the scattering coefficient s that defines the light flow reflected by an infinitely thin layer.

According to the model of contradirectional flows the intensity J of a light beam, which passed through a medium layer, can be written in the form of [6]

$$J = J_0 \frac{(1 - R^2)\exp(-Lx)}{1 - R^2 \exp(-2Lx)}, \tag{1}$$

where J_0 is the intensity of a primary beam; x is the width of a medium layer; $L = (k^2 + 2ks)^{1/2}$ is the effective attenuation factor; $R = (s + k - L)/s$ is the reflection coefficient from an infinitely thick medium layer.

In the case when light attenuation in a medium occurs due to absorption mainly ($k >> s$) expression (1) takes the form:

$$J = J_0 \exp(-kx). \tag{2}$$

Formula (2) is the mathematical notation of the Buger's law [7].

On the assumption that the sample width decreases linearly with the time, i.e., $x = x_0 - vt$ (v is the rate of through hole formation; x_0 is the initial width of a medium layer; t is the time), expressions (1) and (2) can be written as follows:

$$J = J_0 \frac{\left[1 - \left(\dfrac{s + k - \sqrt{k^2 + 2ks}}{s}\right)^2\right] \exp\left[-\left(\sqrt{k^2 + 2ks}\right)(x_0 - vt)\right]}{1 - \left(\dfrac{s + k - \sqrt{k^2 + 2ks}}{s}\right)^2 \exp\left[-2\left(\sqrt{k^2 + 2ks}\right)(x_0 - vt)\right]}, \tag{3}$$

$$J = J_0 \exp[-k(x_0 - vt)] = J_1 \exp(kvt), \tag{4}$$

respectively, where $J_1 = J_0 \exp(-kx_0)$ is the light intensity, which passed through a sample in the start time.

To take into account changes of the absorption coefficient under LI on a sample, we supposed that the time dependence of k is a polynomial of degree n:

$$k = k_0 + k_1 t + k_2 t^2 + k_3 t^3 + k_4 t^4 + \ldots + k_n t^n, \tag{5}$$

where k_0, k_1, k_2, k_3, k_4, and k_n are the constant coefficients.

Such polynomials for renovation the functional features of physical values are widely used at mathematical approximation of experimental data [8].

Using (5) expression (4) takes the form:

$$J = J_2 \exp[k_0 vt - \left(k_1 t + k_2 t^2 + k_3 t^3 + k_4 t^4 + \ldots + k_n t^n\right)(x_0 - vt)], \qquad (6)$$

where $J_2 = J_0 \exp(-k_0 x_0)$ is the light intensity, which passed through a sample in the start time.

3. EXPERIMENTAL RESULTS AND DISCUSSION

To solve the set problem we used the YAG solid-state laser with neodymium impurity and generation lines $\lambda_1 = 1{,}064$ μm and $\lambda_2 = 532$ μm. Laser has operated with modulated Q-factor and the pulse frequency of laser radiation 25 Hertz. Power density and pulse duration of laser radiation in investigated materials were 10^9 W/cm^2 and 10^{-8} sec, respectively, that provided realization of evaporating mode of LI on a surface.

Processes of light propagation in electronic materials under laser processing were studied with the time dependences of radiation intensity, passed through samples, with the wavelength λ_2. Observation was realized with the double monochromator DFS-12. The spectral slot width was 0,5 cm^{-1}.

We used the optical schematic "on clearance". Here the collimator, which collects radiation for analysis, had in a central part the opaque screen with the square of the order of 1 cm^2. It completely overlapped a beam of laser radiation in a collimator plane in the absence of investigated sample. Screen shielded an electron photomultiplier and a spectral device from the influence of a direct laser beam.

Thin plates with the widths of 0,3 mm and 0,8 mm for REM and SF-1, respectively, were used as the investigated samples.

In Fig. 1 we present the time evolution of the light intensity J, passed through REM and SF-1, curves 1 and 2, respectively. As seen from this figure, the light intensity J, passed through the investigated samples, undergoes essential changes.

Thus, time dependence of the light intensity, passed through REM, had three typical intervals. On the first interval the monotonic decay of J was observed. On the second one J was extremely raised. This interval was restricted by the time $t_1 = 23{,}0$ sec, after reaching which the light intensity slowly saturated (curve 1 in Fig. 1).

At the same time in opaque (for radiation with the wavelength λ_2) SF-1 samples time evolution of the light intensity at first had the interval with constant signal strength $J \cong 0$. After this interval the light intensity increased extremely as well. Then, after reaching the time $t_2 = 63{,}7$ sec, the light intensity slowly saturated (curve 2 in Fig. 1).

We have to note, that in investigated samples the through hole formation with diameter of the order of 100 μm occurred during the times t_1 and t_2.

This experimental fact allowed to define the rate of through hole formation in investigated samples. As it turned out, it was equal $\cong 1{,}304 \cdot 10^{-5}$ m/sec and $1{,}256 \cdot 10^{-5}$ m/sec for REM and SF-1, respectively.

Experimental data processing about the light propagation in REM under LI was performed using the mathematical approximation. To do this we developed the computer program using the programming language Java. This program realized one of the most effective methods of nonlinear parameterization, namely, the quasi-Newtonian method of variable metric (the Davidson-Fletcher-Powell method) [9]. In this case the developed Java-program allowed to estimate both the parameters of mathematical model (formulas (3), (4), and (6)) and the determination coefficient D under experimental data approximation.

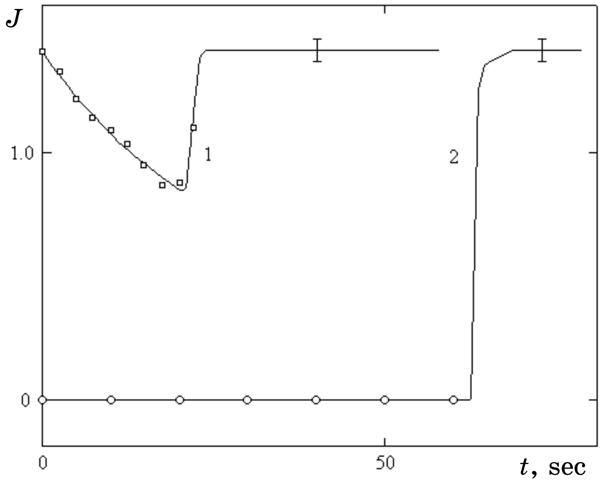

Fig. 1 *– Time dependences of the light intensity J passed trough REM and SF-1: curves 1 and 2, respectively. Dots denote the theoretical values of J*

Mathematical approximation of the experimental data about light propagation in REM was done for ten pairs of J and t values, the initial parameters were 10^{-3}. As it turned out, as a result of mathematical approximation of experimental data the value of D was equal 0,872, 0,853, and 0,995 in accordance with expressions (3), (4), and (6). But parameters of the formula (6) only had a physical meaning. For this model the absorption coefficient k was positive, and it was negative (– 6,935 cm^{-1} and – 16,826 cm^{-1} for formulas (3) and (4), respectively) for other models. Experimental data processing about light propagation in SF-1 under LI was realized using relation (4). Theoretical values of J, we have obtained for SF-1 and REM with (4) and (6), respectively, are marked by the dots in Fig. 1.

As seen from Fig. 1, the satisfactory fit between the theory and the experiment in investigated samples in the time interval of the through hole formation is observed. In this case the coefficients k_0, k_1, k_2, k_3, and k_4 from (6), which characterize the light absorption in REM, were 0,250 cm^{-1}, $4{,}14\cdot10^{-2}$ $cm^{-1}sec^{-1}$, 0,460 $cm^{-1}sec^{-2}$, – $5{,}46\cdot10^{-2}$ $cm^{-1}sec^{-3}$, and $2{,}33\cdot10^{-3}$ $cm^{-1}sec^{-4}$, respectively. Note, that the representation of k in the polynomial form (5) had the physical meaning for $n > 3$ only. Just starting from $n = 4$ the theoretical values of absorption coefficient obtained under the experimental data approximation in REM were positive in the whole time interval of the through hole formation.

At the same time the theoretical values of $J(t)$ for SF-1 were obtained for constant value of the absorption coefficient $k = \infty$ cm^{-1}. Infinite value of the light absorption coefficient for the foil-coated fiberglass plastic is explained by the presence of a thin external copper layer in a sample, which was removed after all the others during the laser processing.

4. CONCLUSIONS

Thus, we have carried out the experimental investigation of light propagation in the foil-coated fiberglass plastic SF-1 and the layered dielectric REM under evaporating mode of LI on a surface. The value of perforation rate of through holes in investigated samples during processing of laser radiation is calculated. Time dependence of the absorption coefficient in REM is determined. The value of light absorption coefficient in SF-1 is estimated. Obtained results denote that it is necessary to take into account the changes of radiation absorption for detailed description of the light propagation process in insulating materials under laser processing. Investigations of the light propagation features under evaporating mode of LI on a surface can be used for control and optimization of laser processing of electronic materials.

REFERENCES

1. V.P. Veiko, *Opornyi konspekt lektsiy po kursu "Fiziko-tehnicheskie osnovy lazernyh tehnologiy". Razdel: Lazernaya mikroobrabotka* (S.-P.: S.-P. GU ITMO: 2008).
2. A.Yu. Ivanov, G.E. Skvortsov, *Tech. Phys. Lett.* **26** No8, 675 (2000).
3. S.G. Gornyi, A.M. Grigor'ev, V.A. Lopota, G.A. Turichin, *Fizika i khimiya obrabotki materialov* No5, 23 (1998).
4. M.N. Libenson, *Lazerno-indutsirovannye opticheskie i termicheskie processy v kondensirovannyh sredah i ih vzaimnoe vliyanie* (S.-P.: Nauka: 2007).
5. M.N. Libenson, E.B. Yakovlev, G.D. Shandybina, *Vzaimodeistvie lazernogo izlucheniya s veschestvom (silovaya optika). Chast' I. Pogloschenie lazernogo izlucheniya v veschestve: Konspekt lektsiy* (S.-P.: S.-P. GU ITMO: 2008).
6. M.M. Sushchinskii, *Sov. Phys. Uspekhi* **31** No3, 181 (1988).
7. G.C. Landsberg, *Optika: uchebnoe posobie dlya vuzov* (M.: Fizmatgiz.: 2003).
8. V.I. Berdyshev, L.V. Petrak, *Approksimatsiya funktsiy, szhatie chislennoy informatsii, prilozheniya* (Ekaterinburg: UrO RAN: 1999).
9. V.V. Nosach, *Reshenie zadach approksimatsii s pomosch'yu personal'nyh komp'yuterov* (M.: MIKAP: 1994).