13

Pulse Conductivity in Ag—Pd Resistors Induced by Laser Pulses

© V.A. Aleksandrov,[1] V.V. Besogonov,[2] D.G. Kalyuzhnyi[1,2]

[1] Udmurt Federal Research Center, Ural Branch Russian Academy of Sciences,
426067 Izhevsk, Russia
[2] Kalashnikov Izhevsk State Technical University,
426069 Izhevsk, Russia
e-mail: ava@udman.ru, vbesog@mail.ru, dikdik@mail.ru.

Received August 28, 2021
Revised February 1, 2022
Accepted February 2, 2022

Pulsed EMF in resistive thick-film Ag—Pd elements is experimentally studied when their surface is irradiated with a laser beam. The dependences of the pulsed EMF on the coordinate of the action of the laser beam on the film surface are obtained. It is shown that applying a constant bias voltage to a thick-film resistive element can significantly increase the amplitude of unipolar EMF pulses induced by laser pulses. It was found that the amplitude and frequency of the EMF signals depend, respectively, on the power and frequency of laser pulses. It is shown that by the value of the pulsed EMF it is possible to control the parameters of the high-power laser radiation incident on the surface in real time. The design of a receiver for recording the parameters of laser radiation based on an Ag—Pd sensitive element has been developed. The sensitivity of the device for measuring the power and pulse repetition rate is estimated.

Keywords: measurement of laser parameters, thick-film resistor, thermo EMF.

DOI: 10.21883/TP.2022.05.53680.246-21

Introduction

Compact elements sensitive to laser radiation and simultaneously having high damage threshold, remain in demand because of widely used high-capacity industrial and research laser units. Thick-film resistive sensors developed on the basis of silver and palladium compounds make it possible to record certain pulses of laser radiation. Such film structures are formed as a result of sintering and burn-in of source compounds in the form of nanopowders with particle size of 100 nm [1] max. into the ceramic substrate. The paste includes components at the following ratio (in wt %): Ag_2O — 19.7, Pd — 25.3, other - glass. After thermal treatment the glass matrix would contain Ag, Pd and PdO compound having semiconductor properties. Besides, tin, zinc, ruthenium etc. oxides may be used as source material to produce resistive film structures [2,3-6].

Studies of thermo-EMF in Ag—Pd-resistors under exposure to pulses of CO_2-laser confirmed semiconductor properties of resistive film surface [7–9]. Concentration of charge carriers in a PdO-semiconductor increases as temperature grows, therefore, the studied specimens may have additional conductivity provided for by thermal generation of carriers on the surface of resistive film under pulse laser exposure. This paper conducted research of pulse conductivity in Ag—Pd-resistors when resistor surface is exposed to laser pulses. We noted that at the same time fixed and variable components of EMF signal are recorded. EMF signal value is proportionate to energy characteristics of incident radiation. However, the signal at the same time was dozens-hundreds microvolts. This paper implements one of methods to increase EMF signal — simultaneous feed of electric displacement to electrodes located at the edges of the resistive film. The purpose of this paper was to study the opportunity of using the EMF signal to record capacity of a laser beam incident on the resistive film surface.

1. Methods

Experimental studies of pulse EMF in Ag—Pd-film resistors were conducted using a normally incident beam of laser radiation of CO_2-laser with capacity of 12 W at wavelength 10.6 μm, operating in pulse mode with pulse repetition rate 1 KHz and pulse duration 100 μs. Diameter of laser beam spot on the resistor surface was 1 mm. The position of the laser impact point on the film surface was changed by a two-coordinate mechanical system with pitch of 0.2 mm along every coordinate.

As a photosensitive element, Ag—Pd-resistive films were used with specific surface resistance from 10 to 1000 Ω/sq. In experiments with specimens of resistive film with size of 6×6 mm and resistance of 60 Ω, electric induction in the form of DC voltage was fed to thick-film electrodes at resistor edges. An EMF signal when exposed to laser pulses was picked up from probe electrodes brought to the surface of resistive film [10]. Distance between points of contact of proble electrodes to specimen resistive film surface was 2.4 mm. At voltage of electric induction of 3 V the voltage drop between probe electrodes was 1 V.

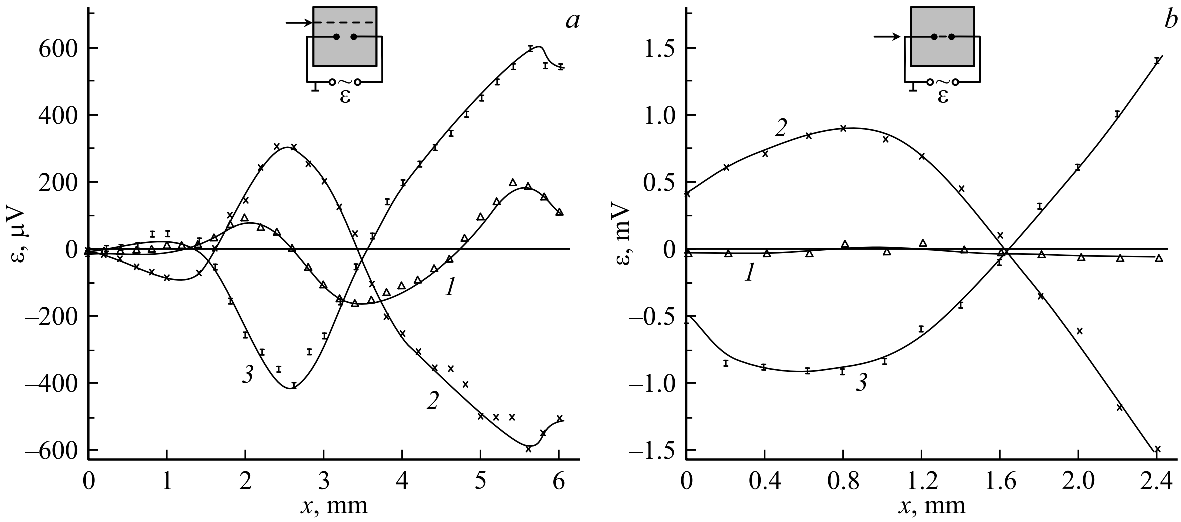

Figure 1. Dependences of EMF pulse amplitude in Ag–Pd-resistor on coordinate of laser beam impact point when measured by two probe electrodes: *a* — when radiated parallel to the line between probe electrodes; *b* — when radiated along the line between probe electrodes (*1* — without induction, *2* — induction +3 V, *3* — induction −3 V).

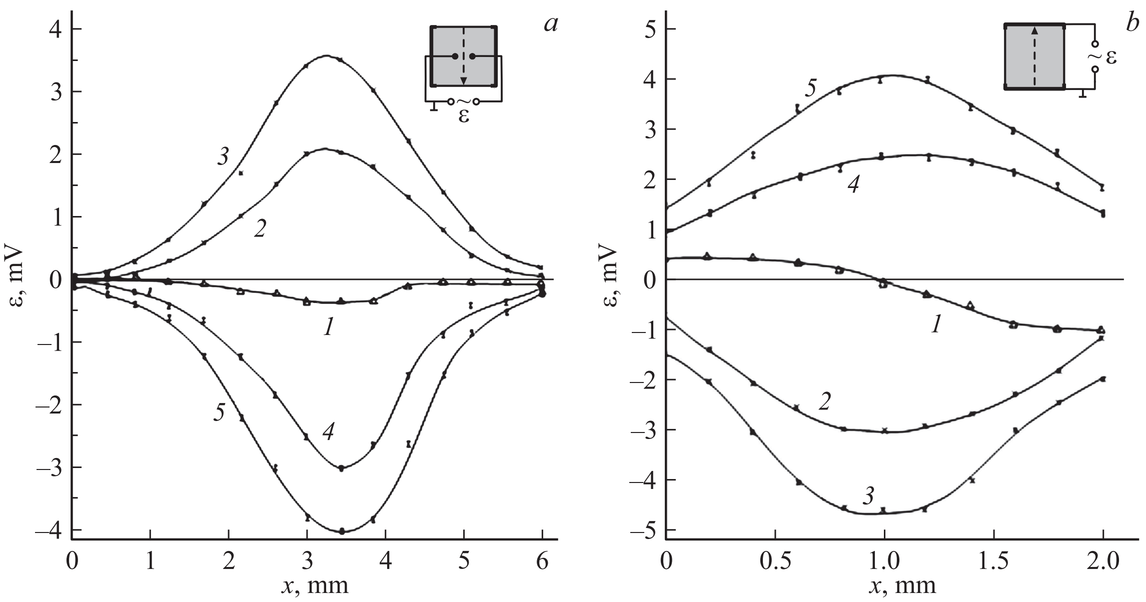

Figure 2. Dependences of EMF pulse amplitude in Ag–Pd-resistor on coordinate of laser beam exposure point: *a* — resistor with film 6×6 mm (*1* — without induction, *2* — induction +1.5 V, *3* — induction +3 V, *4* — induction −1.5 V, *5* — induction −3 V); *b* — resistor with film 2×2 mm (*1* — without induction, *2* — induction +0.5 V, *3* — induction +1 V, *4* — induction −0.5 V, *5* — induction −1 V).

Specimens with resistive film with size of 2×2 mm had resistance of 325 Ω. Electric voltage to this specimen was fed through an additional resistor with resistance 544 Ω so that induction at the film specimen was 0.5 and 1 V.

2. Results and discussion

Fig. 1 and 2, *a* provide EMF dependences on laser pulse impact point on the resistor surface with resistance of 60 Ω when scanned along various lines relative to the probe electrodes. Patterns of laser beam movement on the film surface are provided on details of each of the figures. DC voltage of different polarity was applied to film electrodes placed on the right and left edges of resistive film (not shown on figures).

Fig. 2, *b* provides the results of experiments with film specimen of size 2×2 mm. All figures also show dependences of pulse thermo-EMF on the laser beam impact point, i.e. EMF produced without feeding induction to the specimen. The produced results show that feeding the

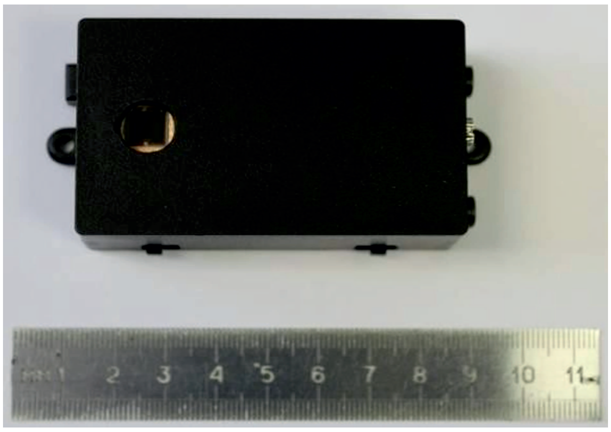

Figure 3. Meter of power and frequency of laser pulses with thick-film sensor.

DC bias voltage to a thick-film resistor makes it possible to increase amplitude of unipolar EMF pulses induced by laser pulses on the resistive film surface.

Dependence of EMF amplitude on coordinate of laser beam impact point also differs from dependence of pulse thermo-EMF. Thus, in one and the same point of the film the EMF value (point with coordinate 1 mm on curve *1* fig. 2, *b*), arising on electrodes without electric induction feed, may take zero value, and when induction voltage is present — maximum value (point with coordinate 1 mm on curves *4, 5* fig. 2, *b*). Therefore, results of experiments demonstrate occurrence of additional conductivity in Ag–Pd-resistors when their surface is radiated with laser pulses by displacement of charge carriers from the area of exposure to laser beam into the adjacent non-radiated area. The latter is due to increased concentration of charge carriers on the surface of resistors in the field of thermal exposure to laser pulses. Since the composite material of resistors contains particles of Ag, Pd metals and palladium oxide PdO, being a semiconductor of *p*-type, when locally heated by laser, both electrons and holes are generated. Increase of pulse EMF in resistors with electric induction present and exposure to laser pulses may be related to generation of simultaneously two types of carriers that contribute to the total current.

Charge carriers are accelerated by electric field of induction and create pulse current. This current induces EMF on the area of resistor surface and is recorded using electrodes brought to this area of the surface. Shape of EMF pulses occurring because of current of carriers excited by a laser pulse does not differ from the shape of thermo-EMF pulses.

Threshold value of power density, which, when exceeded, damages the material, was calculated for each of the finished film components: Ag, Pd and PdO. Material damage meant irreversible change of silver-palladium film structure. From analysis of produced values, the least resistance is demonstrated by palladium oxide. Therefore, theoretically calculated threshold value of power density for radiation wavelength $10\,\mu$m is $6.6 \cdot 10^9\,\mathrm{W/m^2}$. Threshold value of film damage in this case is 66 W with pulse repetition rate of 1 KHz.

Conclusion

As a result of the conducted experiments to study thermo-EMF and photoconductivity in Ag–Pd-films using a powerful unit with CO_2-laser, the possibility of using Ag–Pd-thick-film resistors as sensors to monitor parameters of powerful pulse radiation of technological lasers was shown.

It was experimentally proven that whenever silver-palladium films are exposed to laser radiation, surface thermo-EMF arises therein. The produced frequency and amplitude of EMF signals make it possible to define the frequency and power of laser radiation pulses.

Based on these studies, a device was designed to measure power and frequency of laser pulses [11], the appearance of which is shown in fig. 3.

The meter comprises a receiver of laser radiation based on a thick-film Ag–Pd-resistive sensitive element, an amplifier and an autonomous source of power. Sensitivity of meter with sensor having working surface size 6×6 mm was $10^{-6}\,\mathrm{V{\cdot}m^2/MW}$.

Funding

The paper was made with the support of RFBR grant 18-48-180005 p_a.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] V.G. Nedorezov. *Tekhnologiya kermetnykh rezistivnykh struktur i komponenty na ikh osnove* (Penza, PGU, 2005) (in Russian)
[2] V.G. Nedorezov, S.V. Podshibyakin, N.K. Yurkov. Izvestiya vuz, Povolzhskiy region. Tekhnicheskie nauki, **4** (16), 33 (2010) (in Russian).
[3] Y.C. Shin, J. Song, K.M. Kim, B.J. Choi, S. Choi, H.J. Lee, G.H. Kim, T. Eom, C.S. Hwang. Appl. Phys. Lett., **92** (16), 162904 (2008). DOI:10.1063/1.2912531
[4] J. Xu, Y. Shun, Q. Pan, J. Qin. Sensors and Actuators B: Chemical, **66** (1), 161 (2000).
[5] S.F. Bamsaoud, S.B. Rane, R.N. Karekar, R.C. Aiyer. Sensors and Actuators B: Chemica, **153** (2), 382 (2011). DOI: 10.1016/j.snb.2010.11.003
[6] S.F. Bamsaoud, S.B. Rane, R.N. Karekar, R.C. Aiyer. Mater. Chem. Phys., **133** (2–3), 681 (2012). DOI: 10.1016/j.matchemphys.2012.01.052
[7] V.A. Alexandrov, V.V. Besogonov. IOP Conf. Series: Materials Science and Engineering, 560, (2019). DOI: 10.1088/1757-899X/560/1/012099

[8] A.I. Anselm. Vvedenie v teoriyu poluprovodnikov (Nauka, M., 1978) (in Russian)
[9] D.G. Kalyuzhny, V.A. Aleksandrov, V.V. Besogonov. Prikladnaya fizika, **3**, 81 (2016) (in Russian).
[10] I.V. Bodnar', V.Yu. Rud', Yu.V. Rud'. J. Appl. Spectroscopy, **73** (4), 567 (2006).
[11] V.A. Aleksandrov, D.G. Kalyuzhny, V.V. Besogonov. Patent RF na izobretenie № 2636256, 33 (2017) (in Russian).