THIN-FILM TERMOACOUSTIC DETECTOR FOR A REGISTRATION OF MICROWAVE PULSES OF NANOSECOND DURATION

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A process of the thermoacoustic generation inside thin metallic films deposited on the glass substrate was studied. The measurements performed at 8-mm wavelength have showed that an absorption coefficient reaches its maximum in the 2...3-nm aluminum films. The process of sound excitation was studied in a sandwich-type system consisting of glass – aluminum film – water. It was shown that an efficacy of a themoacoustic excitation for the metallic films of several tens of angstroms is solely defined by the thermophysical parameters of liquid adjoining to the film surface.

PACS: 534.2, 621.385.6

INTRODUCTION

Effect of acoustic transient generation by absorbing of electromagnetic radiation can be employed for the development of new type of detectors. Specifically this technique can be used for the registration of an envelope of very short (several nanosecond) electromagnetic pulses [1]. Optoacoustic detectors for visual and infrared radiation are widely used in science and industry applications. We propose to use the thermoacoustic method for the registration of short pulses of microwave radiation.

Development of an optimal microwave energy absorber is a principal problem in designing of the thermoacoustic detector of microwave pulses of nanosecond duration. For a correct detection of the temporal profile of the envelope a short microwave pulse it is necessary to provide the wave absorption in a layer, which thickness is much less than a length of sound propagation within pulse duration. For this particular purpose a process of the thermoacoustic generation inside thin metallic films deposited on the quartz substrate was studied.

MOTIVATION OF THE STUDY

In our previous works [1,2] it was shown that the short microwave pulse can be detected with thermoacoustic receiver provided the thickness of the layer of the pulse absorption is much smaller than the pulse duration: $\tau_R >> (\alpha c_0)^{-1}$. The conductive materials could be employed as absorbers of microwave energy. In a conductive material with a conductivity σ the wave with frequency f is absorbed at the depth of a skin layer: $d = (\pi f \mu \mu_0 \sigma)^{-1/2}$, where μ is the magnetic conductivity, μ_0 is the magnetic constant ($\mu_0 = 4\pi \cdot 10^{-7}$ H/m). It can be shown that perfectly conductive metals Al and Cu could be employed for the thermoacoustic conversion of microwave energy to the acoustic one. But the efficiency of energy conversion is very small due to strong reflection of microwave waves from the metallic surface. Typical value for the reflection coefficient is 99.5%, therefore only 0.5% of the incident energy can be converted to the acoustic pulse. The aim of our study was to find the absorbers where the efficiency of the microwave energy conversion to acoustic pulse was as much as possible. For this purpose the optical coefficients of thin metallic films were studied.

OPTICAL PROPERTIES OF THE THIN ALUMINUM FILMS

Measurements of the optical properties of aluminum films deposited on the glass substrate were performed. Microwaves with 8 mm wavelength were employed. Radiation was directed on the film surface from air or through the glass substrate (Fig.1). Results of the measurements are shown in Fig.2. Reflection of Al-film was monotonically induced with growth of the film thickness and its value became equaled to unity for thicknesses larger than 10 nm. Correspondently the coefficient of transmittance was reduced and it practically vanished at the film thicknesses 6...8 nm.

The values of transmittance coefficient were completely identical for cases of microwave incidence from air (Fig.2,a) and from glass (Fig.2,b). The absorption coefficient reached maximum value in the thicknesses range 2...3 nm, the measured maximum value of absorption when the wave fell from the glass substrate ($\square_m$=0.49) was higher than the wave fell from air side ($\square_m$=0.34). Theoretical analysis of the wave behavior in a three-layer structure was performed on the basis of Maxwell equations and empirical dependence of a conductivity of the thin film on its thickness. For the three-layer structure we obtained the following solution:

$$R = \frac{\left((n_3 - n_1) + 2\frac{d}{b} \right)^2}{\left((n_3 + n_1) + 2\frac{d}{b} \right)^2}, \qquad T = \frac{4 n_1 n_3}{\left((n_3 + n_1) + 2\frac{d}{b} \right)^2},$$

PROBLEMS OF ATOMIC SIENCE AND TECHNOLOGY. 2004. № 2.
Series: Nuclear Physics Investigations (43), p.200-202.

$$A = \frac{8\frac{d}{b}n_1}{\left((n_3+n_1)+2\frac{d}{b}\right)^2}, \qquad (1)$$

where d is the film thickness, $b = c/2\pi\sigma$, σ is the metal conductivity, n_1 and n_3 are the indexes coefficients of media from direction of radiation incidence and after metallic film correspondently (see Fig.1). Here the conductivity is a function the film thickness which is a result of electron reflections from the film boundaries:

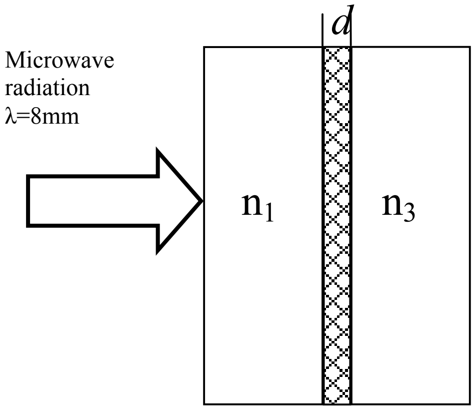

Fig.1. Aluminum film with d thickness sputtered on the quartz glass substrate (n_3=1.5)

$$\sigma(d) = \sigma_0(d/2l_0)(1+\ln(l_0/d)), \quad d < l_0 \qquad (2)$$

where σ_o is the specific conductivity of metal, l_o is the mean length of a free propagation of an electron in thick metal. The coefficient h is also a function of conductivity: $h(d)=c/2\pi\sigma(d)$.

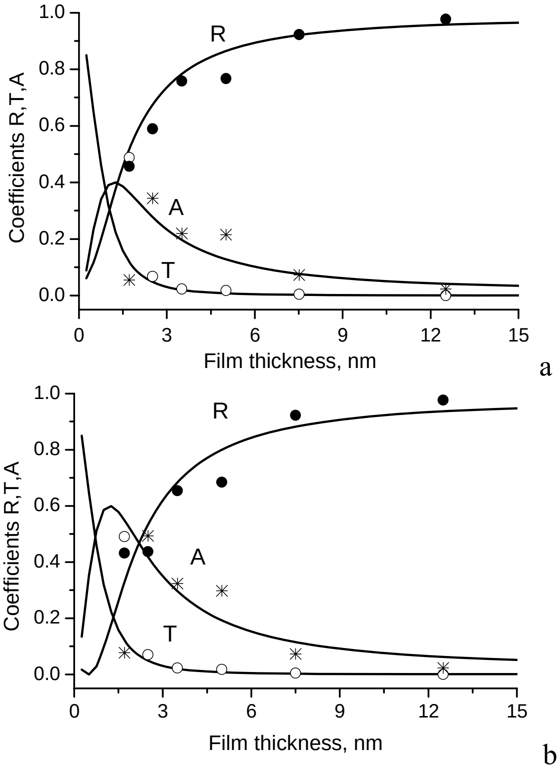

*Fig.2. Dependence of the coefficients of reflection (R), transmittance (T) and absorption (A) on the aluminum film thickness. Microwave radiation falls on the film surface from air directly (a), or being transmitted through a glass substrate (b). Theoretical curves calculated using formulas (1,2) are shown by the solid lines, experimental results are presented with symbols (● - R, ○ - T, * - A)*

Theoretical dependencies of the optical coefficients R,T,A calculated according to formulas (1,2) are presented in Fig.2 by solid lines. We used the following constants values σ_o=3.54·10^7 Cm/m, l_o = 15 nm, $h_o = c/2\pi\sigma_o$=0.135 nm.

ACOUSTIC PULSE GENERATION

A schematic diagram for a thermoacoustic pulse excitation by short microwave burst is shown in Fig.3. The aluminum film sputtered on the surface of 4-mm glass substrate was used as absorber of microwave radiation of 8-mm wavelength. Glass plate reflected 30% of incident energy and another 70% was penetrated into glass and propagated to the aluminum film surface. Here almost 50% of passing energy was reflected and remaining energy produced the thermoacoustic pulse.

Energy of microwave burst is absorbed mainly inside metallic film deposited on the glass substrate transparent for microwaves and in water layer contacted with the film from the opposite side.

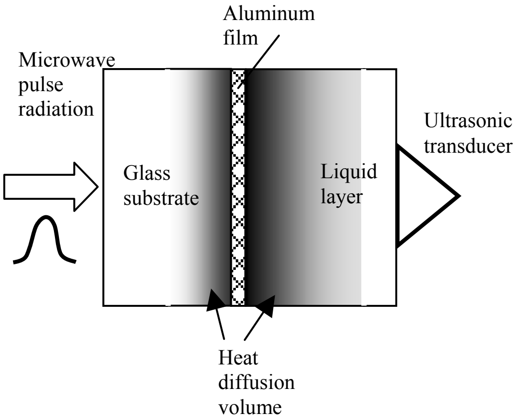

Fig.3. Principal scheme of excitation of thermoacoustic pulses in a thin metallic layer sputtered on the glass substrate

Due to extremely small thickness of the film and high conductivity of metal heat produced inside the film is practically instantly diffuses into the glass substrate and into liquid located another side of the film (see Fig.3). Therefore sound is produced inside regions where heat can penetrate during the pulse duration. Liquid provides the higher values of Grunizen parameter and the efficiency of sound inside liquid layer is dominated. Acoustic pulse excited in absorbing aluminum layer propagated through water layer of 3-mm thickness. Wide-band ultrasonic transducer made of PVDF film of 30μm thickness was used for detection of acoustic pulse. The pressure sensitivity of the receiving transducer was of about 20 μV/Pa in the frequency range from1 to 80 MHz.

Modeling of the thermoacoustic pulse excitation in the sandwich-like structure was performed.

A set of equations that includes equation of motion and thermodiffusivity equation were solved numerically. Results of numerical simulations are presented in Fig.4. We employed a method of transfer function for the calculation. The transfer function of the system containing glass layer, thin aluminum film of varied thickness and water layer was calculated. Transfer function is uniform up to 200 MHz for small (d<5 nm) thicknesses. Thickness growth results in reduction of transfer function in high frequency region. The waveform of the thermoacoustic pulse is presented in Fig.4.

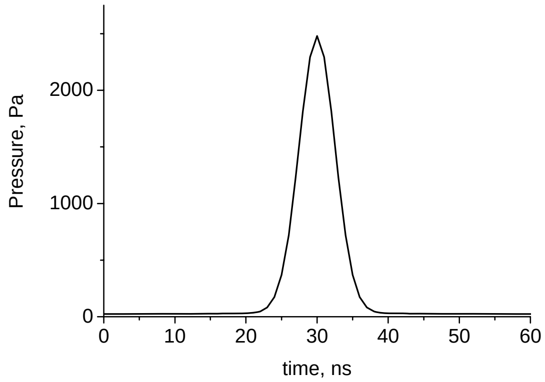

Fig.4. Temporal profiles of acoustic transient excited in aluminum film. Microwave pulse with Gaussian waveform was specified at the entrance of the system

Gaussian profile of the incident microwave burst with 10 ns duration was specified for numerical simulations. Profile of the thermoacoustic pulse replicates the corresponding waveform of the microwave burst for small thicknesses and then it became broader. We can estimate that for 2 nm aluminum film with maximum absorption the peak pressure value can be up to 2000 Pa. Maximum signal voltage will be about 40 mV. This value 1.5 times exceeds the noise level produced by capacitor discharge. It makes us optimistic to detect the thermoacoustic pulse experimentally in spite of extremely low incident microwave energy (1 mJ).

This work was supported by RFBR grant # 01-02-17344

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ТОНКОПЛЕНОЧНЫЙ ТЕРМОАКУСТИЧЕСКИЙ ДЕТЕКТОР ДЛЯ РЕГИСТРАЦИИ ИМПУЛЬСОВ СВЧ ИЗЛУЧЕНИЯ НАНОСЕКУНДНОЙ ДЛИТЕЛЬНОСТИ

В.Г. Андреев, В.А. Вдовин, П.С. Воронов

Исследован процесс термоакустической генерации в тонких металлических пленках, нанесенных на кварцевую подложку. Измерения, проведенные на длине волны 8 мм, показали, что коэффициент поглощения имеет максимум при толщине алюминиевой пленки 22...25 ангстрем. Поглощение в максимуме составило 34 и 49% при падении волны соответственно со стороны пленки и кварцевой подложки. Наблюдаемые явления в тонких металлических пленках теоретически объяснены с позиций аномального скин-эффекта. Проведен анализ генерации звука в слоистой системе кварц - алюминиевая пленка – вода. Показано, что при толщинах металлической пленки в несколько десятков ангстрем эффективность термоакустической генерации определяется теплофизическими параметрами граничащей с пленкой жидкости.

ТОНКОПЛІВКОВИЙ ТЕРМОАКУСТИЧНИЙ ДЕТЕКТОР ДЛЯ РЕЄСТРАЦІЇ ІМПУЛЬСІВ СВЧ ВИПРОМІНЮВАННЯ НАНОСЕКУНДНОЙ ТРИВАЛОСТІ

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Досліджено процес термоакустичної генерації в тонких металевих плівках, нанесених на кварцову підкладку. Виміру, проведені на довжині хвилі 8 мм, показали, що коефіцієнт поглинання має максимум при товщині алюмінієвої плівки 22...25 ангстрем. Поглинання в максимумі склало 34 і 49% при падінні хвилі відповідно з боку плівки і кварцової підкладки. Явища, що спостерігаються у тонких металевих плівках, теоретично пояснені з позицій аномального скин-ефекту. Проведено аналіз генерації звуку в шаруватій системі кварц - алюмінієва плівка – вода. Показано, що при товщинах металевої плівки в кілька десятків ангстрем ефективність термоакустичної генерації визначається теплофізичними параметрами рідини, що граничить із плівкою.