The Electron Gun of E-beam-Pumped Laser Setup ELA

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Abstract. In the report the electron gun (EG) of experimental laser setup ELA is described. The pulsed EG works with the repetition rate of 5 mHz. The electron energy behind the anode foil is ~300 keV, the current density is ~200 A/cm^2 at the pulse duration of 80 ns. The total E-beam energy behind the foil reaches 300 J at the cross-section 4x22 cm^2, and the energy density for a pulse exceed 3 J/cm^2.

In spite of high loading, the anode foil of EG maintains more than 5000 impulses. It occurs due to its sandwich form. It has three layers: its two outside layers consist of 14 μm Ti foil, and the inside layer is 20 μm mylar. Using of three and more layers in the anode foils of EGs allows sharply to increase their reliability.

With the help of calorimeter and solid-state dosimeters the distribution of the absorbed dose from E-beam through the thickness of the irradiated material is measured. The received data is necessary for interpretation of the results on the E-beam interaction with the matter. The technique used for its construction will be useful in many cases.

1. Introduction

The setup EL-1 for research of E-beam-pumped excimer lasers was created in the 1980s in Division of Quantum Radiophysics of P.N.Lebedev Physical Institute [1]. Now it refers to as ELA. A large amount of works on physics of excimer lasers were carried out with this setup and it was bring to a high degree of reliability [2]. In a number of experiments with the removed laser chamber the e-beam was used for an irradiation of various materials [3,4]. The characteristics of E-beam, and also constructional features of the electron gun and other elements of setup providing for its high reliability, are also submitted in the report.

2. The basic characteristics of e-gun of ELA

The high current cold cathode electron gun (EG) with energy supply system is intended for production of the powerful e-beam (EB) and its using for excitation of gas mixtures. The energy supply system is typical for such setups. It includes the high voltage pulse generator (MG), coaxial forming line (FL) and two high voltage spark gaps (G_1 and G_2). After switching on G_1 MG charges the low-inductive capacity – FL, which in its turn is connected to the vacuum diode after switching on the oil spark gap G_2.

MG consists of 10 condensers ИК-100/0,25. At the maximum of primary charging voltage of 50 kV the stored energy is ~3 kJ and the output pulsed voltage reaches 500 kV.

In a coaxial forming line distilled water is used as a dielectric. FL has the following parameters: the length is 1.6 m, the diameters of the interior and the external electrodes of 104 and 280 mm, the capacity is 7 nF, the characteristic impedance equals 7 Ω. FL working charge voltage is ~650 kV. At this voltage its storage energy reaches 1.5 kJ. During the work of FL on the matched load the discharge current is equal 40 kA at the pulse duration of 80 ns.

The e-beam gun has a cold cathode. The tapered cathode of 4x22-cm size contains blade rows of thin copper foil placed 2 mm apart from each other transversely to the length. This cathode has already sustained more than 30 thousand pulses.

The passage isolator of EG is made from high pressure polyethylene. Such isolator is exposed an intensive x-ray irradiation and shock loadings arising during the work of the oil spark gap. It has maintained more than 30 thousand pulses. The similar isolators from organic glass has maintained before destruction less than 1000 pulses.

E-beam with a current density up to 300 A/cm^2 and electron energy ~300 keV was generated in a vacuum diode and transported into a laser chamber through a vacuum-tight foil window. The output foil was placed on a perforated steel plate. The geometric transparency of this protector was about 70%, and it permitted the foil to operate at a gas pressure in the laser chamber up to 6 atm. An incident energy density of the e-beam on the foil reached 7 J/cm^2. Due to a mismatch of Marx generator and the forming line the main e-beam pulse was followed by a low-current (5 times less as the main one), low-electron-energy (~100 keV), and long-duration (~1μs) tail, which was predominantly absorbed by a foil, thus increasing an energy load up to ~15 J/cm^2. This resulted in the very high temperature rise that was only 30% lower than the melting point of titanium (~1600 ^{0}C). Single-layer foils: aluminum, titanium, aluminum-beryllium, as well as organic films: polyethylene, Mylar (polyethylene terephtalate), Teflon (polytetrofluoride-ethylene), and Kapton (polyimide) could withstand to such extreme load only for 1 to 20 shots, being examined at the working gas pressure in the laser chamber 1-3 atm. The highest number of shots was attained for titanium and aluminum-beryllium foils of 20-50 μm thickness.

Significant increase of the foil window lifetime have been achieved when using a multi-layer combination of two titanium foils of 14 μm thickness separated by 20-μm thickness Kapton film [2]. The foils have been glued one to another along the contour, so that a breakdown of one of them did not cause a loss of the vacuum in the diode volume.

The long tests of such sandwich foils on setup ELA have shown that at the moments of their complete break shown as a microleak, internal Ti foil has plenty of apertures of the various sizes. Their research has resulted in a conclusion, that the entrance surface of the anode foil is exposed to bombardment by microparticles accelerated in a cathode-anodi interval. Kapton film thus extinguishes an arising shock wave that keeps the second external foil from the break. As a result the sandwich foil of the electron gun of the setup ELA maintains more than 5000 pulses which means several months of uninterrupted work, since the pulse repetition rate of setup is about 100 shots per day. Only one day is required to replace the foil

Using of three or more layers in the anode foils of the electron guns allows sharply to increase their reliability at the expense of division of the basic functions between layers from various materials. This essentially extends the areas of application of E-beams. This is the idea which provides high reliability of the electron gun of setup ELA at extremely high specific loading from an e-beam current on a foil.

3. Characteristics of ionizing radiation of ELA.

The studies of ionizing-radiation (IR) source based on the electron gun of laser setup ELA [3] pursued the purpose of finding the distribution of absorbed dose deposition through the thickness of irradiated materials. Let's remind, that the energy of e-beam electrons is about 300 keV, a current density after the foil is up to 200 A/cm^2, pulse duration is 80 ns. The complete e-beam energy at the entrance in active volume of laser chamber is up to 300 J at the cross-section of 4x22 cm^2.

Two different methods have been used to construct such distribution. One of them used a calorimeter to measure the energy of e-beam and X-rays penetrated through various foils of different thickness. The calorimeter with the filters was placed near the foil of the electron gun. The results obtained by this method are shown in Fig.1.

The solid circles designate average meanings of the appropriate values, which were then approximated by a solid curve.

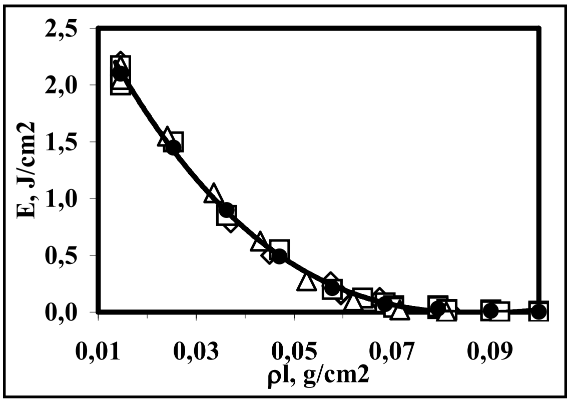

Fig.1. Energy density measured by calorimeter behind various foils versus density to thickness product. The triangles, squares and rhombus designate results for polyethylene, Al and Ti foils.

By numerical differentiation of this curve we have received the distribution of absorbed dozes D as a function of the depth l in the material with the density ρ=3 g/cm^3 (Fig.2).

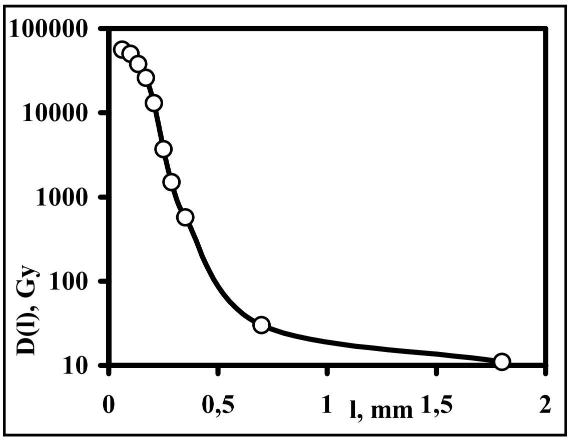

Fig.2. Distribution of absorbed dozes in the material with ρ=3 g/cm^3.

Eight dots of the D(l) dependence starting with the maximal meaning D(0)=56000 Gy nearby the surface and to the depths up to l= 0.3 mm were obtained by this method. Two additional dots for larger depths were measured with the help of solid-state thermoluminescence dosimeters. They were the glass discs of 8-mm diameter and 1-mm thickness and had the density ρ=3 g/cm^3. A set of such dosimeters consisting of 25 discs was mounted inside a thick aluminum plate, which was closed by 0.2-mm thickness titanium foil. After e-beam irradiation near the exit of the electron gun with controllable energy density during 5-10 shots the dosimeters were read out. The absolute calibration of dosimeter readings were obtained by averaging over several runs and joining with the calorimetric measurements.

Fig.3 demonstrates the results obtained by averaging over 18 runs of measurements carried out by thermo-luminescence dosimeters.

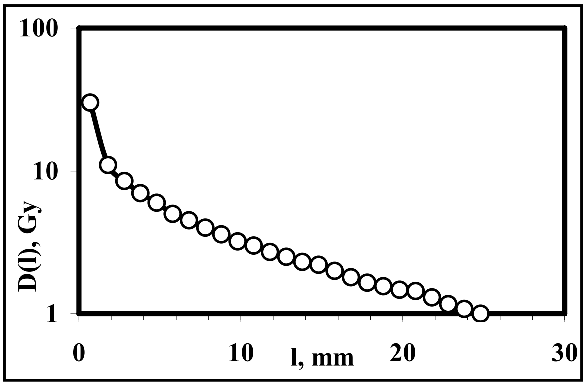

Fig.3. Distribution of absorbed dozes in the material with ρ=3 g/cm^3 measured by thermo-luminescence dosimeters.

Fig.4 shows the combined distribution of the absorbed dozes versus the depth in a material with the density 3 g/cm^3, which is irradiated by one pulse of e-beam gun with energy density 2.1 J/cm^2 and electron energy of about 300 keV. Note that for depths more than 0.2 mm the absorbed dozes were caused mostly by X-ray radiation. This part of the curve displays the shape of distribution D(l) in windows of e-beam pumped KrF-laser [3]. The absolute value of D depends on the particular laser construction, but it rises with the growth of laser energy of the setup and its power.

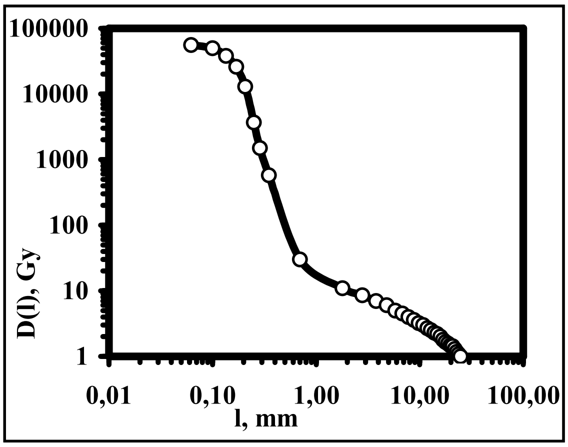

Fig.4. Combined distribution of absorbed dozes versus the depth in material with ρ=3 g/cm^3.

The similar measurements were carried out in the field of laser chamber windows of the setup ELA. Here the energy density of IR reaches ~0,1 J/cm^2. About half of this energy bring the electrons scattered from a basic e-beam, the rest - by x-ray radiation. Here the distribution of the absorbed doze through a material of windows similarly to that part of the curve on a fig.4 which remains behind the filter from Ti by thickness of 0,2 mm. This IR has caused fast degradation of the majority of windows used by us.

Let's note essential heterogeneity of the D(l) distribution. The maximum is observed at near surface layer where the antireflection and high reflection coatings are placed. For good serviceability of these coatings they should have very high radiation durability. Besides, it is necessary to take into account the presence of IR induced transient absorption in the windows, the distribution of which practically repeats D(l) profile.

4. Conclusions

The submitted here detailed description of the e-gun of the experimental laser setup ELA with e-beam excitation of gas mixtures demonstrates simplicity of the design and high reliability of the pumping systems of the given laser type. On the basis of such setups the creation of technological excimer VUV lasers with wave lengths of 172 (Xe_2*), 157 (F_2), 146 (Kr_2*) and 126 nm (Ar_2*) and energy in a pulse from ~1 J and higher now is real. The designs of e-beam pumped KrF-lasers for the purposes of laser fusion are now studied also.

The common feature of all e-beam pumped lasers is that their windows work at IR influence. These IR consist from the fast electrons scattered from the basic e-beam and x-ray radiation. The carried out measurements of the absorbed doze distribution from these IR through the typical optical materials of the windows show essential heterogeneity of this distribution with a maximum at the windows surface inverted inside of the laser chamber. The presence of marked IR is necessary for taking into account at the creation of laser setups with e-beam excitation. Especially it concerns to a choice of the optical material for the windows of such lasers, and also the optical coatings on their surface.

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