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Thin film Al targets for a laser-plasma source of extreme ultraviolet radiation

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Using a multilayer mirror spectrometer of the extreme ultraviolet (EUV) range, the laser plasma emission spectra of bulk aluminum in the wavelength range of 8.0−18.0 nm were studied. Testing of thin film laser targets made of aluminum and comparative measurements of the intensity of EUV radiation of a film with a thickness of 100 nm and a bulk material target were carried out.

Keywords: SXR and EUV radiation, thin film, laser plasma.

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Introduction

Work on the generation of X-ray radiation during the interaction of a focused laser pulse with a substance has a long history [1–3]. Spectral and brightness characteristics of the plasma torch of solid-state, gas and cluster targets were studied. The transition from a gas jet to a condensed cluster state with supersonic gas flow through a profiled nozzle demonstrated a significant change in the plasma temperature and, as a consequence, its radiation spectrum [4]. Of interest are the possibilities of controlling the spectral-brightness characteristics of the source due to the transition from a massive solid-state target to a thickness-calibrated thin-film target made of the same material. Questions about whether it is possible to significantly increase the intensity of the source for targets that are thin compared to the depth of the crater of the laser pulse, and at what point a significant drop in the signal will begin with a decrease in the thickness of the film, have not been systematically studied. The expansion of the experimental data base on the interaction of laser pulses with targets of submicron thicknesses will contribute to the development of mathematical models of extreme ultraviolet radiation of laser plasma, and will also probably create prerequisites for setting up experiments on laser amplification in the EUV range when the amplified radiation passes in the direction „through the target ".

In this paper, for the first time, approaches to the production of targets in the form of metal films with typical thicknesses of $0.05-0.5\,\mu$m are found, and samples of such targets are made of aluminum. The choice of a material with a small atomic number significantly simplifies the interpretation of the laser plasma radiation spectrum. Initial testing of such targets is carried out using stands of laser-plasma sources available in the IPM RAS, equipped with spectral diagnostic channels in the EUV range.

1. Experiment

At the first stage, the radiation spectrum of a solid-state target made of bulk aluminum was studied. Experiments were carried out on the installation [5] when the target is excited by an Nd : YaG laser with the following characteristics: wavelength 1064 nm; pulse energy 0.8 J; pulse duration 5.2 ns; pulse repetition frequency 10 Hz; focusing spot diameter $66\,\mu$m. Spectrometric measurements were performed on a spectrometer based on multilayer X-ray mirrors of normal incidence [6]. The curve of the spectral sensitivity of the device, determined by the bandwidth of the absorption filters, the spectral dependence of the reflection coefficient of the X-ray mirror and the spectral sensitivity of the EUV radiation detector is shown in Fig. 1.

Fig. 2 shows the radiation spectrum of the target from Al in the wavelength range 8.0−18.0 nm. According to the literature data [7], with laser exposure parameters comparable to those used in our experiment, intense groups of lines in the vicinity of wavelengths 12.5−13.1 and 16.0−16.2 nm are observed in this range. The groups are formed by intense lines of Al ions with charges +4 and +3; in the wavelength range between 13.1 and 16.0 nm, there is a relatively weak background of bremsstrahlung and characteristic radiation (the latter is presumably associated with impurity ions). The results obtained by us (Fig. 2) with a spectral resolution of the device no worse than 1.0 nm did not allow us to resolve individual lines, but qualitatively correspond to the data presented in the literature.

Experimental samples of thin-film laser targets were made using the magnetron sputtering technique on a substrate with a sacrificial layer preformed on its surface, dissolving in a liquid etcher. The technique of forming free-hanging thin films with thicknesses less than 500 nm is described in detail in [8]. Since the thin film is destroyed when interacting with

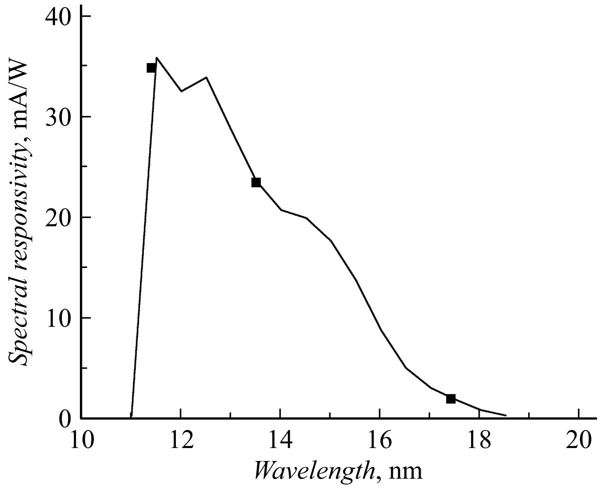

Figure 1. Dependence of the sensitivity of the mirror spectrometer on the wavelength (solid line — calculation; points — experiment).

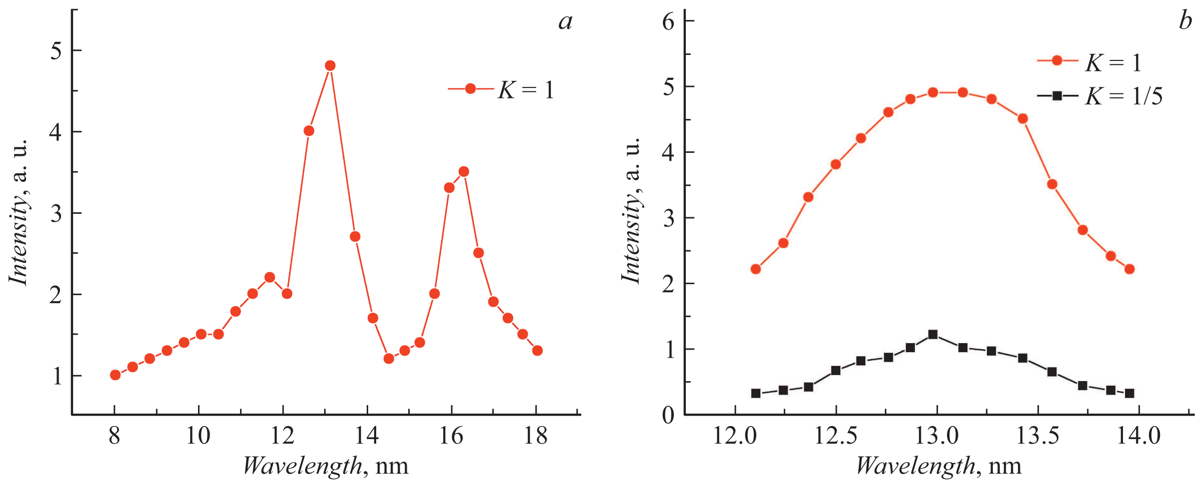

Figure 2. The emission spectrum of a solid-state Al target: *a* — in the entire range of the spectrometer (photodetector gain $K = 1$); *b* — in the wavelength range 12–14 nm ($K = 1$ and 1/5).

Figure 3. Experimental sample of a thin-film laser target (before and after).

Signal from the Al target

Wavelength, nm	Signal, B	
	Film	Array
13.1	3.5±0.3	4.5±0.3
16.2	2.1±0.2	2.9±0.2

a powerful laser pulse, the target was made sectioned — in the form of an Al film with a thickness of 100 nm, glued to a grid with a diameter of 25 mm and a cell size of 3 × 3 mm. Individual cells with an Al-film could be positioned in the laser focusing area alternately due to the fact that the flange on which the target was attached was equipped with a bellows displacement unit. This made it possible to make a series of shots without opening the vacuum volume to the atmosphere to replace the target. A photo of a film aluminum target with a thickness of 100nm, mounted on a holder for installation in an experimental chamber, is shown in Fig. 3.

The table shows the results of an experiment on recording a signal from a film target with a thickness of 100 nm and from a target made of a bulk material.

As you can see, the signal from an extremely thin film (thickness 100 nm) differs only slightly (no more than 30%) from the intensity of radiation from a bulk target.

Conclusion

Comparing the values of signals for film and bulk targets given in the table, it can be noted that the contribution of radiation with wavelengths near 13.1 nm to the total EUV radiation of plasma is slightly greater for a target with a thickness of 100 nm than for an array. Intuitively, this seems natural, since a bulk material should somehow perform the functions of a „refrigerator“ for plasma and contribute to the shift of its composition towards a decrease in the relative proportion of ions with high ionization multiplicities. Therefore, it is of interest to compare signals from a bulk and thin-film target also in other parts of the EUV range, but this would require re-equipment of the mirror spectrometer (replacement of optical elements: multilayer mirror, EUV filters). In particular, the lines of fivefold ionization Al are present in the vicinity of the wavelength 31 nm, and these lines were confidently observed earlier for the bulk target [7]. The first results presented by us will be supplemented by comparative data on the output of EUV radiation from film targets of various thicknesses. The production of samples of Al-films with thicknesses from 30−50 nm to units of μm according to the developed technique is not a serious difficulty. The main costs of preparing an experiment with a statistically significant number of film targets of various thicknesses are associated with the need to design a device for laying and alternately feeding samples to the laser exposure area.

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Conflict of interest

The authors declare that they have no conflict of interest.

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