Modification and optical degradation of thin multilayers under VUV/UV radiation from compressed plasma flows

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Abstract. Coaxial plasma accelerators are under consideration for generation of compressed plasma flows which are suitable for emitting of powerful broadband radiation (including the VUV/UV ranges). The using of different gases in a chamber allows to control the spectrum. For inert gases the upper value of energy is limited by its first ionization potential (for neon $\approx 21.55$ eV). For air the maximum energy is limited by $\approx 6$ eV. Such technical systems are suitable for studying of optical properties stability for thin multilayers and the other coatings. Such tests were fulfilled for bilayers based on HfO$_2$/SiO$_2$ pair on silica substrates which is stable for laser radiation in the visible and IR ranges. It was found that a single exposure of the radiation (for neon and air) caused a relative decline of the radiation durability in $\approx 1.03...1.14$ times. Spectral measuring demonstrated that the maximum decline of transmission (up to of $\approx 3...4\%$) was detected for exposures in neon in the range of 320...450 nm.

1. Introduction
The compressed plasma flows is studying as sources of powerful and high brightness broadband radiation [1]. Such plasma systems are characterized by a high temperature ($\approx 0.5...5$ eV), high speeds ($\approx 20...70$ km/s) and a possibility to their use for a stability tests of coatings under gas dynamic and/or radiation loads. Coaxial plasma accelerators with a PTFE hub in the interelectrode gap [2] are currently employed for these purposes. The selection of a gas medium in a chamber allows to operate the spectral characteristics of the discharge. So, for inert gases the spectrum “cutting off” occurs at the wavelengths corresponded to the first ionization potentials. For oxygen containing gases (air, water vapors etc.) the quanta with the wavelengths above $\approx 200$ nm could be registered [3]. That “cutting off” wavelength corresponds to the Schumann-Runge bands [4]. So, such plasma systems are prospective for realization of different exposure regimes on materials. Orientation of the accelerator canal and mutual disposition the substrates allow to realize purely radiation, gas dynamic or complex exposure.

In this study thin film multilayers based on HfO$_2$/SiO$_2$ pair [5] were studied from the point of view of stability (or variation) of their spectral characteristics or the other optical properties. Traditionally such systems are used for design of optical elements (with antireflection or reflection coatings) which are durable to laser impact. But there is requirement to new data obtaining about a changing of their
characteristics under exploitation in off-design conditions (especially in the VUV/UV spectral ranges). We could state about the absence of these data. We hope that such data permit to optimize optical elements of powerful lasers, optical detectors, etc.

2. Experimental procedures

Coatings based on HfO$_2$/SiO$_2$ pair with two layers and a full thickness $\delta$ of 140 and 285 nm were prepared by ion assisted electron beam evaporation on silica substrates. These systems were considered as antireflection interference coatings (for $\lambda = 527$ nm for $\delta = 140$ nm and $\lambda = 1054$ nm for $\delta = 285$ nm).

Generation of compressed plasma flows and the VUV/UV radiation was fulfilled with the experimental setup [6]. Coaxial erosion-type magnetoplasma compressor (MPC) with a PTFE hub was used as the plasma source. The MPC length was 100 mm and its outer diameter was 34 mm. A pulsed capacitor (with the capacity of $C = 18 \mu F$) was commutated by a high frequency thyratron (Pulsed systems, Ltd.). A stored energy was up to $E \approx 3.0...3.6$ kJ. The scheme of sample orientation relatively the MPC canal is presented in figure 1. A regulation of discharge spectrum was fulfilled by a chemical composition of gas medium in the chamber. The using of neon allows generation of relativity stiff quanta with the maximum energy corresponding to the first ionization potentials $I_{\text{Ne}} = 21.55$ eV ($\lambda > 60$ nm). For air achievable maximum quanta energy is up to $\approx 6$ eV ($\lambda > 200$ nm). For these both cases radiation exposure was studied. One side of the sample was turned to the MPC canal and the opposite side was covered by a copper screen. Between the radiation exposures the sample was turned 180° around.

![Figure 1. Scheme of sample orientation in chamber: 1 – MPC, 2 – coated substrate and 3 – copper screen.](image)

Measuring of optical spectral characteristics before and after the VUV/UV exposure was fulfilled with Agilent Cary 7000 and Agilent Cary 300 spectrometers within the wavelength range of $\lambda = 300...1300$ nm with a step size of 1 nm. Radiation durability was studied with ISO 21254-2:2011 standard (the 1-on-1 test). Lasers LQ929(532) ($\lambda = 532$ nm) and LQ929(1064) ($\lambda = 1054$ nm) were used as sources. Ophir PE25BF-C 8 detector and Ophir Spiricon SP620U 9 device were applied for detection and characterization of transmitted laser beam. Incident angle was 0°. Some parameters of the probe laser beam are presented in figure 2.
3. Data and discussion

Obtained spectral data (see figure 3) evidenced about some changes in optical characteristics. Moreover, significant changes (up to of ≈ 3…4%) were registered for exposures in neon in the range of 320…450 nm. The variances for exposures in air were less and amounted up to ≈ 1…2%. The larger drop in neon could be explained by an impact of stiff quanta (with energy up to of ≈ 21.55 eV) which could cause partial evaporation and radiation erosion of the coating. In the case of thinner coatings (δ = 140 nm) the variances were even smaller (< 1%).

Figure 2. Parameters of probe laser beam: special distribution of energy density (a) and beam profile (b).

Figure 3. Spectral transmission of coatings (δ = 140 (a) and δ = 285 nm (b)) before exposure (black) and after exposures in neon (blue) and air (red).
Decreasing of radiation durability for both coatings was established (see table 1). It was not shown a significant difference for the exposure in air and neon. Characteristic relative drop was \(\approx 0.88\) (for the coating with \(\delta = 140\) nm) and \(\approx 0.98\) (for the coating with \(\delta = 280\) nm). Such drops were explained by edge modification for the coatings because of its partial evaporation under the VUV/UV radiation. Exposure also could cause appearance of internal thermal stresses, surface development etc.

**Table 1.** Data on variation of radiation durability for HfO\(_2\)/SiO\(_2\) bilayers.

| Exposure mode | Radiation resistance, J/cm\(^2\) |
|---------------|----------------------------------|
| Coating with \(\delta = 140\) nm |                     |
| Before exposure | 14.4                             |
| Neon           | 12.6                             |
| Air            | 12.7                             |
| Coating with \(\delta = 280\) nm |                     |
| Before exposure | 21.0                             |
| Air            | 20.5                             |

4. **Conclusion**

Compressed plasma flows are suitable for design of novel radiation sources which are useful for tests of coatings under extreme radiation loads. Exposure of the VUV/UV radiation on the special coatings based on the HfO\(_2\)/SiO\(_2\) pair caused degradation of their optical properties. Under single exposure in neon and air the relative drop of radiation durability was registered at the level of \(\approx 0.88\ldots0.98\). Stiffer quanta (with energy up to of 21.55 eV for neon) caused more intensive changes of spectral characteristics.

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