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Optical thin films for laser mirrors*

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The oxides ZrO_2, Ta_2O_5 and HfO_2 were tested as coating materials with high refractive index for laser mirrors. We prepared lossless periodic dielectric multilayer systmes of HfO_2-SiO_2, ZrO_2-SiO_2 and Ta_2O_5-SiO_2. Especially, we describe some results of laser damage experiments, realized with a Nd-YAG laser.

1. Introduction

The increasing importance of high power lasers has considerably stimulated the interest in the behaviour of optical coatings under high energy laser radiation. Usually, the optical layers represent the weak points in the laser systems [1]. In addition to antireflecting coatings (AR) especially high reflecting multilayer systems (HR) will be used as resonators or deflecting mirrors of great importance for practical applications. Beside the high reflection ($R > 99\%$) and high radiation resistance, high mechanical, chemical and thermal stabilities are required. That is why, in general, only oxides are suitable coating materials. High reflecting laser mirrors consist usually of $\lambda/4$-coatings with alternately high and low refractive indices. Hitherto existing investigations have shown that SiO_2 is a coating material with low refractive index and high laser resistance [2]. In the present study the usefulness of oxides ZrO_2, Ta_2O_5 and HfO_2 with high refractive indices will be tested as coating materials for laser mirrors ($\lambda = 1.06$ μm).

2. Experimental

The coatings are deposited by conventional electron beam evaporation (SiO_2, HfO_2, ZrO_2) and resistance evaporation (Ta_2O_5). To obtain stoichiometric films the evaporation process was carried out reactively at an elevated oxygen partial pressure. In general, the usage of ionized oxygen improves the stoichio-

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metric relations. Evaporation at higher substrate temperature and subsequent annealing very often improve the optical properties but decrease the laser resistance of the films.

As a criterion for the laser resistance of optical films the damage threshold of the layers is commonly used. This is the arithmetical mean value from the highest energy fluence, where no damages occur, and the lowest energy fluence, where damages can still be observed. For these investigations a repetitively Q-switched Nd-YAG laser ($\lambda = 1.06$ µm) was used with pulse width (FWHM) of 85 ns and focal spot diameter of 15 µm. The coatings were scanned line by line with a pulse repetition rate of 0.8 kHz, no overlapping spots, the energy fluence being reduced from line to line. Observation of the damages was carried out by a light microscope.

3. Results and discussion

The laser resistance of the investigated HR-systems and that of the high refracting multilayer components are illustrated in Fig. 1. The occurrence of a position-depending area of the energy fluence region where damages may or may not occur (dotted line) is significant. The damage probability is at the highest applied energy fluence given for each sample. In Fig. 2 we see this behaviour of a multi-

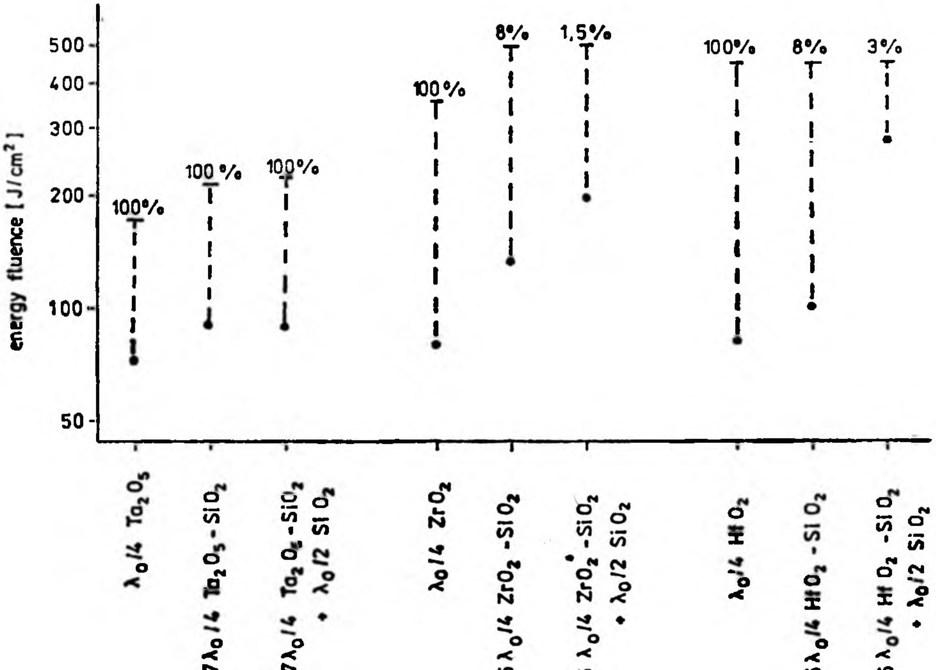

Fig. 1. Laser resistance of different single films and multilayer coatings (● damage threshold, — — — — energy fluence at which destroyed and nondestroyed regions were found on the sample, $\overset{\%}{\mathrm{T}}$ damage probability in %)

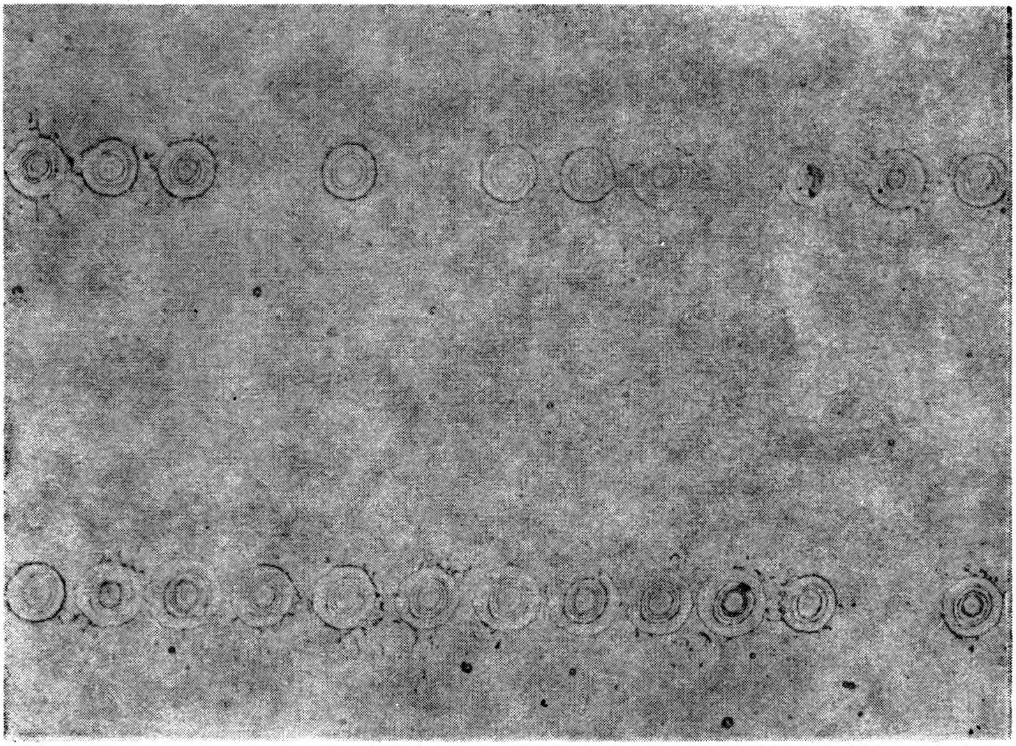

Fig. 2. Photomicrographs of the multilayer system (25 $\lambda_0/4$ HfO_2-SiO_2, $\lambda_0 = 1.06$ μm). Upper row: irradiation 230 J/cm², lower row: irradiation 290 J/cm². Scale |———————| 45 μm

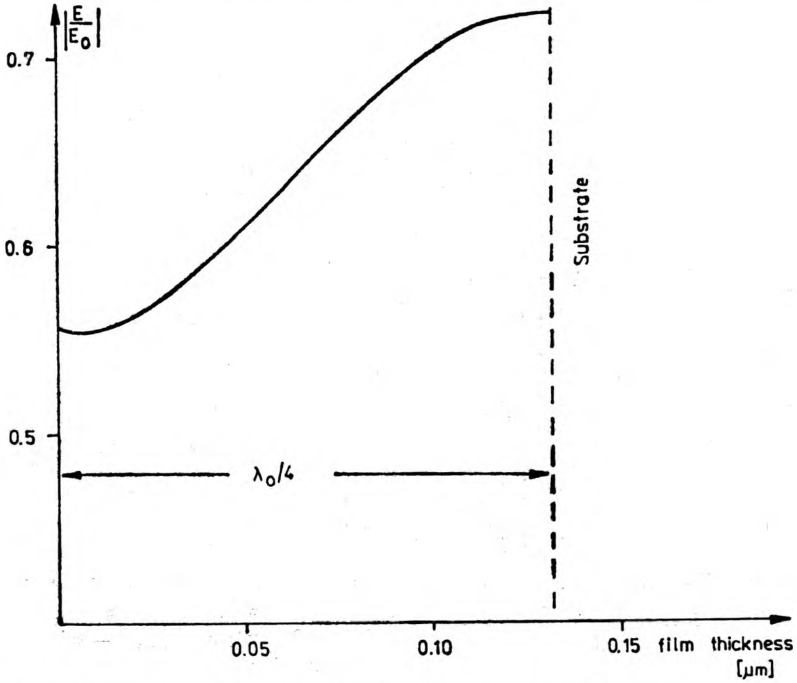

Fig. 3. Computed electric field distribution of a single film with a refractive index 1.9

layer system consisting of 25 HfO_2-SiO_2 $\lambda_0/4$ layers irradiated with 290 J/cm^2 (upper line) and 230 J/cm^2 (lower line), respectively. With the further reduction of the energy fluence the damage rate decreases and approaches zero at the damage threshold (in Fig. 1 marked by •). Thus, for the laser resistance of the coatings, which moreover is more extensively described by the damage probability [3] the damage threshold is not only criterion, as frequently written in scientific papers.

As follows from the experimental results (Fig. 1) the laser resistance of the HR-systems is higher than the high refracting coating component of the systems. This behaviour will be understood if we compare the distribution of the field strength in the multilayer system to that in a high refracting single layer shown in Fig. 3. In the case of a single layer an essential part of the electric field strength penetrates into the substrate, while in a HR-system the electric field strength decreases exponentially. The film-substrate interface, very important for the damage, cannot be reached.

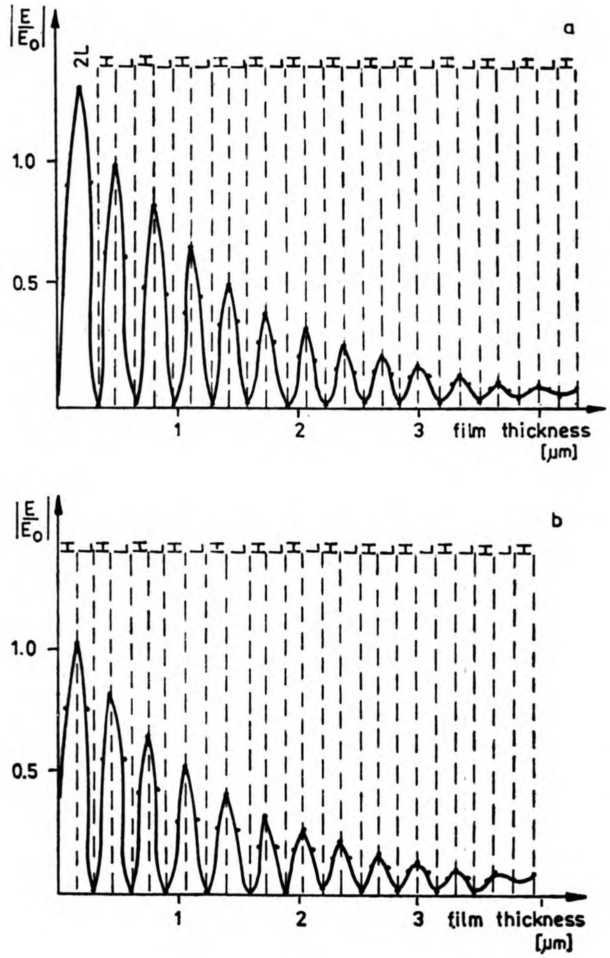

Fig. 4. Computed electric field distribution of the multilayer system (25 $\lambda_0/4$ HfO_2-SiO_2, $\lambda_0 = 1.06$ µm) for the laser wavelength $\lambda = 1.06$ µm. a — with $\lambda_0/2$ SiO_2 overcoating, b — without overcoating

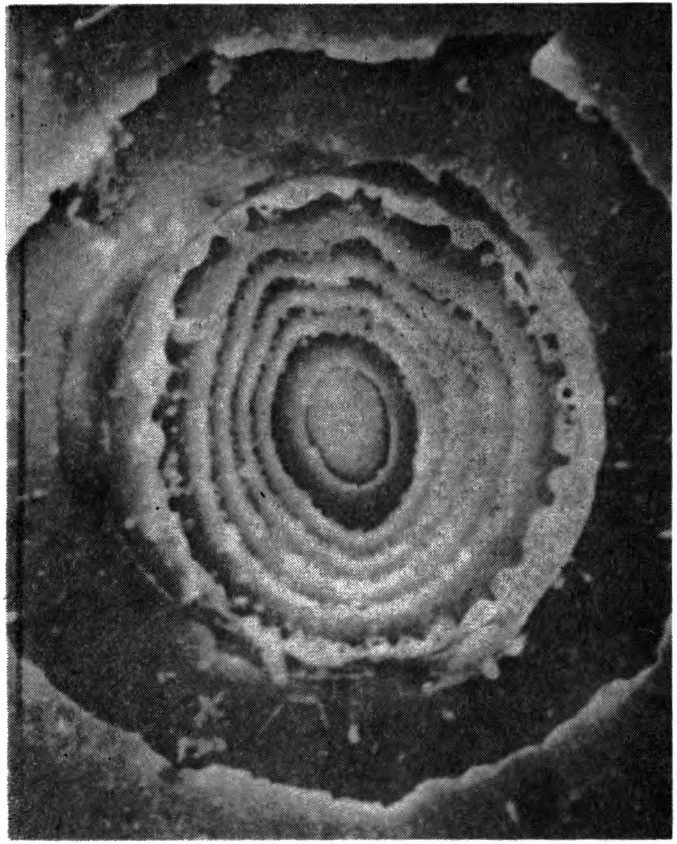

Fig. 5. Damage morphology of the multilayer mirror ($25\ \lambda_0/4$ HfO_2-SiO_2, $\lambda_0 = 1.06$ μm). Scale |————| 6 μm

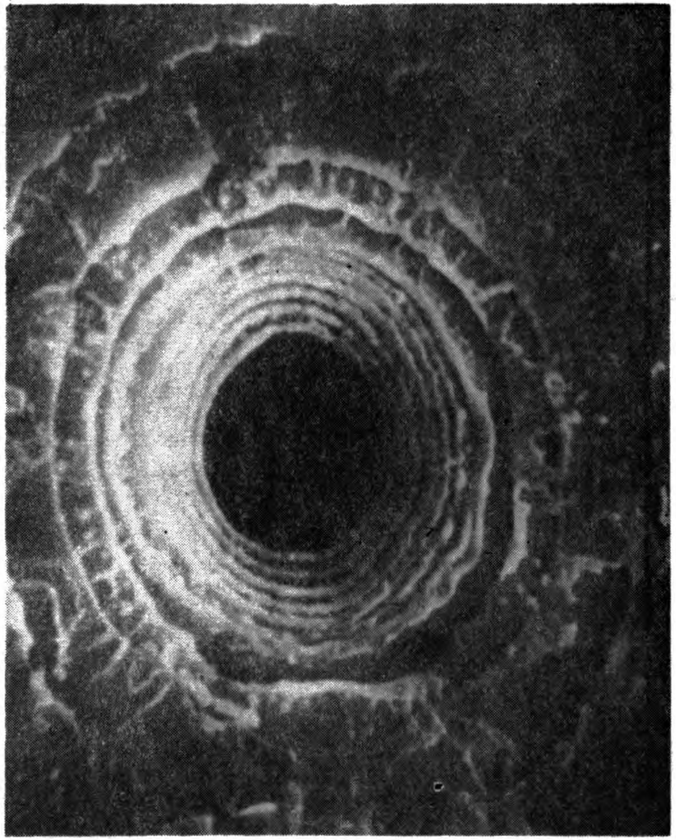

Fig. 6. Damage morphology of the multilayer mirror ($15\ \lambda_0/4$ HfO_2-SiO_2, $\lambda_0 = 1.06$ μm). Scale |————| 5.2 μm

An additional improvement of the laser resistance of the HR-system could be achieved by an additional deposition of $\lambda/2$ SiO_2 coatings [4], (see Fig. 1). The reasons for this behaviour have not yet been found, it should not be attributed to the field strength profile, as may be seen in Fig. 4.

Such a behaviour might result from certain mechanical properties (stress behaviour and microhardness) or be due to certain protective function of the coating concerning a possible response of the external high refracting coating with the atmosphere.

A typical photograph of the damage morphology of a multilayer system consisting of 25 $\lambda/4$ layers HfO_2-SiO_2 obtained by investigations with a scanning electron microscope is shown in Fig. 5. We see the crater produced by the laser pulse. Figure 6 shows an analogous multilayer system consisting of only 15 $\lambda/4$ layers and having a stronger damage resulting from a higher energy fluence in the multilayer system.

4. Conclusions

Our investigations have demonstrated that HfO_2 and ZrO_2 are very important materials for laser mirrors. The highest laser damage level was found in HfO_2-SiO_2 and ZrO_2-SiO_2 multilayer systems.

References

[1] LOWDERMILK W. H., MILAM D., RAINER F., Thin Solid Films **73** (1980), 155.

[2] WOLF R., SCHÄFER D., *6. Jahresarbeitstagung der Hauptforschungsrichtung: Grenzflächen Dünne Schichten,* Karl-Marx-Stadt, 20.–22. April 1982, Tagungsberichte 1983, 149.

[3] WOLF R., SCHÄFER D., Potsdamer Forschungen Reihe B, Heft 31 (1982), 173.

[4] CARNIGLIA C. K., APFEL J. H., ALLEN T. H., TUTTLE T. A., LOWDERMILK W. H., MILAM D., RAINER F., NBS Spec. Publ. **586** (1979), 377.

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Оптические тонкие пленки для лазерных зеркал

Исследованы окислы ZrO_2, Ta_2O_5 и HfO_2, как покрывающие материалы с высоким коэффициентом преломления для лазерных зеркал. Предложены периодические диэлектрические многослойные системы, работающие без потерь: HfO_2-SiO_2, Zr_2O_2-SiO_2, а также Ta_2O_5-SiO_2. Описаны, главным образом, некоторые результаты испытаний, проведенных при использовании лазера Nd-YAG, которые касаются лазерных повреждений.