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HIGH LASER DAMAGE THRESHOLD $\text{HfO}_2/\text{SiO}_2$ MIRRORS MANUFACTURED BY SPUTTERING PROCESS

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ABSTRACT

A major preoccupation for the design of the LMJ laser is the mirrors laser damage threshold.

SAGEM SA, in collaboration with the CEA, has conducted a study in order to improve the laser induced damage threshold under operational conditions.

SAGEM SA demonstrated, in an earlier study, their ability to manufacture high damage threshold mirrors ($>50\text{J}/\text{cm}^2$). However, the damage threshold is reduced in the case of surface contamination.

A different high index material was proposed in order to improve the performances when there is surface contamination.

This study was done in the following 3 phases:

- implementation of the HfO_2 deposition process by ion beam sputtering and definition of the deposition conditions which are supposed to be best adapted,
- manufacture of 25.4 mm diameter $\text{HfO}_2/\text{SiO}_2$ mirrors, the deposition conditions for these mirrors having been deduced from the first phase of the study,
- manufacture of some mirrors with dimensions close to the actual operational dimensions (80 mm diameter).

At each phase of the study, the single layers and the mirrors were characterized:

- absorption mapping,
- diffusion mapping,
- spectrophotometric measurements on the single layers,
- determination of the laser induced damage threshold,
- surface inspection by optical microscopy.

The damage thresholds obtained for 80 mm diameter mirrors are promising. The damage threshold for a contaminated surface is presently being evaluated.

In this paper, we are presenting the main results of this study.

1. INTRODUCTION

The development and use of high-power lasers such as the Mégajoule laser (LMJ) in France aroused a strong interest for specific mirrors likely to be submitted to extremely high fluences, like, for example, the so-called pick-off mirrors, for the half-Turn of the LMJ.

In practice, it can be noticed that the electron-beam deposited mirrors manufactured according to the state-of-the-art techniques show a defect density incompatible with the fluence requirements.

During a previous study, SAGEM SA demonstrated that the use of advanced technologies such as superpolishing and Ion Beam Sputtering enables high laser damage threshold mirrors to be manufactured : laser damage thresholds higher than $50\text{ J}/\text{cm}^2$ at 1064 nm and 3 ns pulse duration.

These mirrors which use $\text{Ta}_2\text{O}_5/\text{SiO}_2$ materials had been integrated in a prototype BEAMLET cavity of the LLNL at the beginning of 1995. Yet, these mirrors proved to be highly sensitive to their environment and their laser damage threshold was reduced in case of surface contamination.

It was suggested that a high refractive index material other than Ta_2O_5 can be used for mirror manufacturing. This high refractive index material was selected based on the following assumption: during the laser shot, the absorption of the contaminants generates a high local temperature increase which causes a damage. The point here is to replace the Ta_2O_5 material by another more refractory one, such as HfO_2 , in order to limit the impact of the temperature increase.

The purpose of this study was firstly to manufacture single HfO_2 layers and each test performed was representative of a set of deposition parameters such as deposition rate, oxygen partial pressure and target material, and secondly, to characterize these layers in order to determine both the impact of these parameters on the laser damage threshold of these layers and the deposition conditions for the manufacture of the $\text{HfO}_2/\text{SiO}_2$ mirrors.

2. DESCRIPTION OF THE STUDY

2.1. CARRYING OUT OF THE STUDY

The study was carried out in 3 phases:

- carrying out of 12 HfO₂ single-layer deposition runs by changing the deposition parameters with a view to assessing the impact of these parameters on the laser resistance,
- manufacturing of HfO₂/SiO₂ mirror samples of $\varnothing = 25.4$ mm, using the deposition parameters which yielded the best results on single layers,
- manufacturing of 80 mm diameter mirrors in order to demonstrate the capability of producing mirrors of scale 1.

All the layer and mirror samples obtained within the framework of this study have been manufactured using Ion Beam Sputtering technologies.

Depositions were performed on HERASIL™ silica substrates polished by SAGEM SA (superpolished quality with a roughness less than 0.1 nm)

2.2. CHARACTERIZATION DESCRIPTION

Characterizations used in this study are the following:

- optical measurements carried out with a spectrophotometer by SAGEM SA and with an ellipsometer by the SMA - IPLN (Service des Matériaux Avancés - Institut de Physique Nucléaire de Lyon) in order to determine the layer thickness and refractive index,
- inspection made by SAGEM SA using the interference contrast optical microscope with a magnification of 100, in order to qualify the number of defects and the surface aspect,
- physico-chemical analyses such as SIMS and ESCA in order to characterize the layer purity and stoichiometry (analyses performed by Science et Surface Company),
- absorption and scattering measurements performed by 2 laboratories: the LOSCM (Laboratoire d'Optique des Surfaces et des Couches Minces de Marseille) and the SMA-IPN LYON.

The test equipment characteristics are the following:

LOSCM absorption and scattering test equipment: 3 available wavelengths for the pump laser. For 1064 nm, the 100µm diameter laser is scanned over a 1mm² surface by 250 µm steps.

SMA-IPN LYON absorption test equipment: 3 available wavelengths for the pump laser. For 1064 nm, the diameter of the pump laser is: 70 µm,

Scattering test equipment of the SMA-IPN LYON: 3 available wavelengths for the pump laser. For 1064 nm, the 1 mm diameter laser is scanned over a $\varnothing$ 70 mm surface by 1mm steps.

All damage tests were carried out on LASCAR facility with the following characteristics:

- pulsed YAG laser : 12.5 Hz,
- pulsewidth : 3 ns,
- wavelength : 1064 nm,
- peak fluence : 50 J/cm²,
- maximum energy : 700 mJ,
- beam diameter at 1/e² : 2 mm.

The threshold is defined by the fluence corresponding to the occurrence of defects > 5µm.

Sites are observed before and after laser exposure using a Differential Interference Contrast microscope, at x 50 magnification. So-called « high-risk » sites are selected and the critical defects are centred inside the laser maximum fluence zone :

Mode 1 on 1

- * a shot at a fluence higher than the estimated threshold,
- * analysis of the site after laser exposure allows the fluence value of the next site: increase of the fluence there is no damage, decrease if a damage occurred,
- * this procedure is repeated until the laser threshold damage has been determined : average of the lowest fluence at which a damage occurs and the highest fluence where there is no damage.

Mode N on 1

- * determination of the 1 on 1 threshold,
- * selection of a « risk » site,
 - conditioning of this site in three steps of 2 shots : 50%, 75%, 100% of the 1:1 threshold, then increase of the fluence in steps (20% of the 1;1 threshold) until a damage has been generated,
 - the threshold computation is similar to that of the 1:1 threshold.

	PHASE 1		PHASE 2		PHASE 3	
Samples	30 single layers from Hf target		f 25,4 mm HfO ₂ /SiO ₂ mirrors: qty 8		f 80 mm HfO ₂ /SiO ₂ mirrors: qty 2	
	30 single layers from HfO ₂ target				f 25,4 mm HfO ₂ /SiO ₂ mirrors: qty 2	
Characterizations	<u>SAGEM SA</u>	<u>CEA</u>	<u>SAGEM SA</u>	<u>CEA</u>	<u>SAGEM SA</u>	<u>CEA</u>
	index and thickness	Laser Damage Threshold (LDT)		LDT		LDT
	ESCA/SIMS <i>Science et Surface</i>					
	Scattering <i>SMA-IPNL</i>	Scattering <i>LOSCM</i>	Scattering <i>SMA-IPNL</i>	Scattering <i>LOSCM</i>	Scattering <i>SMA-IPNL</i>	
	Absorption <i>SMA-IPNL</i>	Absorption <i>LOSCM</i>	Absorption <i>SMA-IPNL</i>	Absorption <i>LOSCM</i>	Absorption <i>SMA-IPNL</i>	
	Optical microscope		Optical microscope		Optical microscope	

Table 1
Characterizations performed during the 3 phases of the study