Ultraviolet graded coatings: a comparison of different surface performance

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Thin film optical coatings play an important role for the design of optical components to be used in the laser field, in particular graded coatings allow for the improvement of the quality of the laser beam without introducing. Diferent coating surface morphologies, useful to this end, are individuated. Thin film multilayer stacks, capable to give the required performance, are designed by shaping, as desired, the film thickness along the sample surface. Three different components, to be used either inside or outside the laser cavity, are proposed for a XeCl excimer laser.

Keywords: Optical thin films, graded coatings, laser resonators

1. Introduction

Graded thin film coatings have been used for more than ten years for improving the quality of laser output beams [1]. Their use in the ultraviolet spectral range is more recent because of the more severe requirements on their performance at these wavelengths [2]. Most of the presently used graded coatings show a gradually decreasing reflectance (in some case step-profiled reflectance) from the center to the periphery of the sample surface.

Besides they typically have a circular symmetry and a null reflectance on the external area of the coating. Such kind of components, mounted as output couplers of unstable laser resonators, allows for high power nearly diffraction-limited, laser beams [3,4,5].

Graded coatings with different reflectance profiles for the ultraviolet are described in this paper. They are intended for the production of optical components to be used either inside or outside the laser cavity. The first coating shows a number of equally spaced circular spots with a high reflectance that decreases to zero outside the spot and with the peculiarity of not introducing phase distortions in the reflected beam.

The second coating has a graded reflectance on a rectangular cross-section area (strip graded mirror) with a variable reflectance along one side of the strip and a constant reflectance along the other side. The third one presents a circular symmetry with a central maximum transmittance that decreases to zero going outwards according to a predefined variation law (Gaussian aperture).

These non conventional optical components are intended for improving the optical quality of the laser radiation delivered by high-gain, short-pulse active media as excimers. These active media generate pulses having such a short time duration that only a few transits inside the resonator are accomplished by the radiation during the pulse lifetime. As a consequence, laser radiation of rather poor spatial coherence is generally delivered by these active media fitted with conventional stable cavities. Then, the development of optical resonators which allow a faster build up of diffraction limited beams or of optical components as Gaussian apertures which may affect the laser radiation spatial coherence [4], is strongly required.

2. Coating design and performance

All graded reflectance coatings proposed here are obtained by a thin film multilayer stack deposited on a quartz substrate. The variation of reflectance along the surface is related to the variation of the coating thickness. The design process consists in the individuation of the number of layers needed for obtaining the required reflectance and of both number and position of layers with graded thickness. Then the thickness profile of this/these layers must be calculated for obtaining the target reflectance profile [6].

2.1 Multiple spot mirror

The multiple spot mirror shows a number of circular spots of high reflectance on its surface spaced apart by a few millimeters. Each spot has a radius of about 1.5 mm. The surface around the spots should have a reflectance lower than 1%.

The main feature of the device is to keep as low as possible the phase variations introduced by the non-uniform coating in the beam reflected by the whole surface (phase-unifying mirror).

The proposed optical coating is obtained with 15 layers of alternating oxide materials (silica and hafnia). Only one of the intermediate layers (hafnia) in the multilayer structure has a step profiled thickness, that goes from a maximum value on the spot to zero outside (Fig. 1).

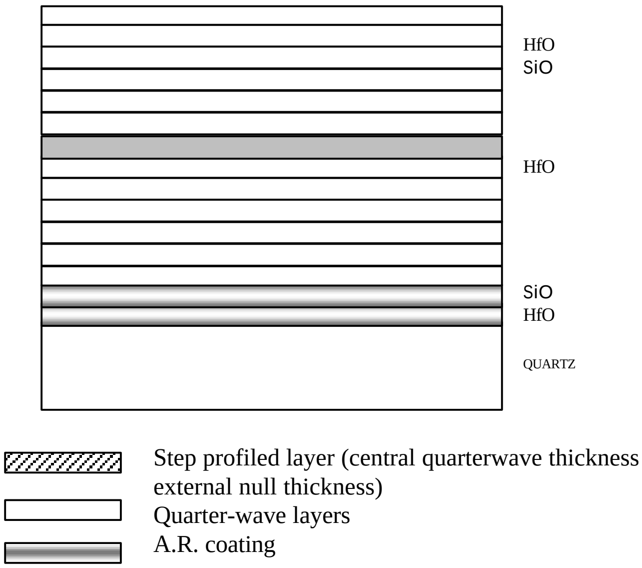

Fig. 1 Coating structure of a high reflecting phase-unifying mirror (15 alternating layers)

The presence of this profiled layer allows a reflectance of 98% inside the spot area and a reflectance of 0.5% on the external area, at a wavelength λ = 308 nm (Fig. 2). The phase distortions suffered by the reflected beam are lower than 20 degrees.

In this case the profiled thickness does not have a gradual variation but changes abruptly from a quarter-wave thickness to zero. This step profiled thickness is repeated in correspondence of each spot and can be obtained with a traditional deposition system by positioning a mask [6], with a number of circular holes, near the substrate.

Multiple spot mirrors with Gaussian reflectance profile could be used as well, provided that they do not introduce phase distortions. In this case a specific graded thickness profile is needed. If the design of Fig. 1 is used for this kind of coating, the maximum phase variation along the surface will be of about 50 degrees. Therefore the design should be optimized.

Plane-parallel cavities with single spot Gaussian-reflectance-profile mirrors as full reflectors were recently [7] applied to a XeCl laser, and it was shown that these cavities allow getting, from excimer lasers, radiation with a beam-quality factor M^2 that is more than 50% smaller than that delivered by conventional plane-parallel cavities. The effect of the Gaussian mirror spot size on M^2 was also investigated, and it was shown that the narrowing of the Gaussian mirror spot size reduced the beam-quality factor value. The low use of the active medium represents the main drawback of plane-parallel cavities using as full reflector a Gaussian mirror having a 2÷3 mm spot-size.

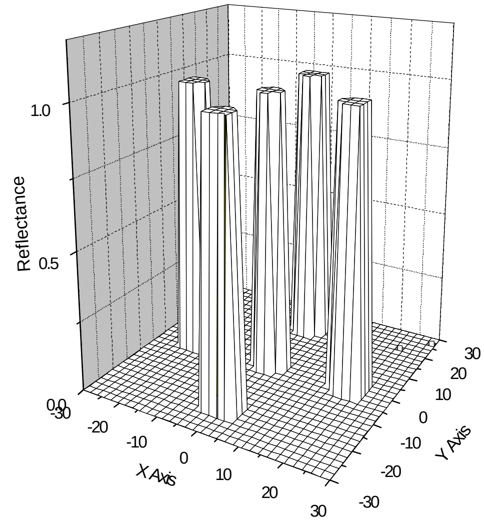

Fig. 2 Reflectance profile of a multiple-spot mirror (phase-unifying).

It is believed that the use of multiple spot Gaussian mirrors or step profiled mirrors as full reflectors in plane-parallel cavities should allow a better filling of the laser

However, active medium and low divergence laser beams. the peculiarity of not introducing phase distortions on the intracavity reflected beam must be fulfilled by the multiple spot mirrors to work properly within a laser cavity. The difference between such components and the phase-unifying devices proposed as output couplers [3] is that the latter are used for unifying the phase of the transmitted beam at the exit of the laser cavity and show only a single reflecting spot.

2.2 Strip graded coating

A step-profiled phase-unifying mirror with a single high-reflecting area but rectangular horizontal cross-section or a Gaussian mirror that shows a Gaussian reflectance profile in one direction and an almost constant reflectance in the other direction can be used in the same way of the previous component. It can be obtained with the same structure of Fig. 1 and its reflectance appears as in Fig. 3, if a Gaussian graded profile is required. The difference in the reflectance shape is only determined by the film thickness profile.

In the deposition process a mask with a rectangular aperture will be used, having one dimension much lower than the other. It will be positioned near the substrate for obtaining step-profiled films and at a well defined distance between source and substrate for the Gaussian profile.

The use in a laser cavity of a full reflector with a modulated intensity reflectance profile which matches the active medium cross section without introducing phase distortions in the reflected beam, should allow to get laser beams of better optical quality with respect to those provided by conventional full reflectors without reducing

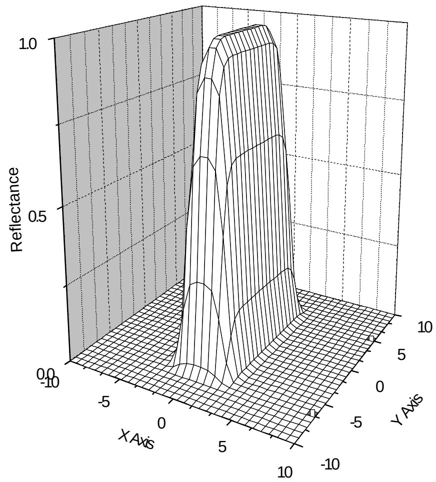

Fig. 3 Reflectance profile of a graded strip coating (Gaussian profile on one side).

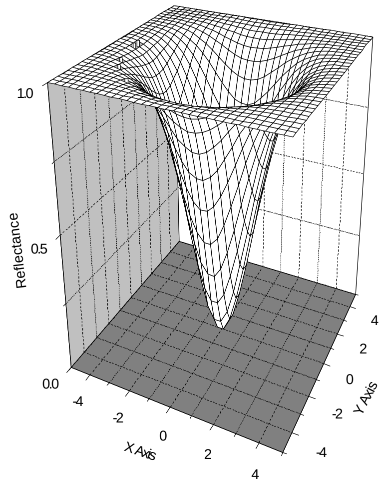

Fig. 4 Reflectance of a Gaussian aperture

the utilization of the laser active medium, accordingly to [7].

2.3 Gaussian aperture

A completely different component consists of a sort of filter to be used outside the laser cavity. It shows a transmission profile having a high central maximum that decreases toward the sample edge according to a Gaussian equation (Fig. 4) with a spot size of about 1 cm.

This Gaussian-profile transmission component is obtained by using an optical coating consisting of 15 thin layers, as shown in Fig. 1, but in this case the graded layer has a shaped thickness varying from a half-wave at the coating center to a quarter-wave at the coating periphery, at the wavelength of interest.

Its central transmission, at λ = 308 nm, is of 97% due to a slight absorption in the coating, while at the coating periphery the transmission remains at the level of 1.5%. The film thickness profile is calculated starting from the required transmission profile.

The manufacture of this coating requires, as in the previous case, the use of a proper mask automatically introduced between source and substrate during the fabrication process when the graded thickness film must is deposited.

The growth of coherence and the evolution toward equilibrium of a beam propagating through an aperiodic sequence of lenses and Gaussian apertures has been recently studied [8]. The main beam parameters (spot size, radius of curvature, and global degree of coherence) have been calculated as a function of the number of transits and it has been shown that a faster growth of the laser beam coherence is obtained by reducing the cavity Fresnel number $F = \varepsilon^2/L\,l$, where ε is the Gaussian mirror spot size, L is the distance between Gaussian apertures and l is the laser radiation wavelength. Then, the transmission of laser beams through Gaussian apertures may represent a simple technique to improve the spatial coherence of low optical quality laser beams, as the ones delivered by commercial excimer lasers fitted with conventional plane-parallel cavities.

3. Conclusions

Different mirrors obtained by non-uniform thin film coatings can be used for improving the quality of XeCl laser beams. In addition to Gaussian and super-Gaussian mirrors, already in use as output couplers of unstable laser resonators, other coatings with different surface performance are proposed.They will be used as full reflectors inside the laser cavity or as transmission filters outside the laser cavity. All coatings are designed for λ=308 nm and experiments with a pulsed XeCl laser are in progress.

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