Zero transmission narrow band laser mirror using a waveguide grating under normal incidence

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Abstract: *A resonant grating mirror comprizing a multilayer submirror and a grating waveguide submirror exhibiting constructive mutual reflection is shown experimentally to provide zero transmission at resonance. Its reflection line width of less than 2 nm, its polarization selectivity and low overall loss make the device useable as a longitudinal mode filter in a disk laser in the 1000-1100 nm wavelength range.*

Introduction

Waveguide grating mirrors based on the excitation under normal incidence of a guided mode of a high index layer belonging to a multilayer mirror have been shown to induce into said multilayer mirror a dichroic character [1]. This resonant effect can be used in multilayer laser mirrors to monolithically control the polarization of the emission. The direction of linear polarization is controlled by means of a rectilinear grating [2] whereas a circular grating permits the generation of the radially polarized mode as shown in a high power Nd:YAG laser [3]. The resonance is designed to be broad so as to cover the entire gain bandwidth of the laser active medium.

The present paper reports on a different application of a waveguide mirror to the control of laser emission. The objective is here to achieve very close to 100% resonant reflection under normal incidence and the narrowest possible reflection peak in order to select a single longitudinal laser mode. Such function is needed in interferometry and for second harmonic generation for instance.

Operation principle of a narrow band waveguide laser mirror.

The principle is the same as in the polarization filtering resonant mirror exhibiting constructive interference between the broad band ground reflection provided by a multilayer submirror and that provided by the waveguide resonance [2].

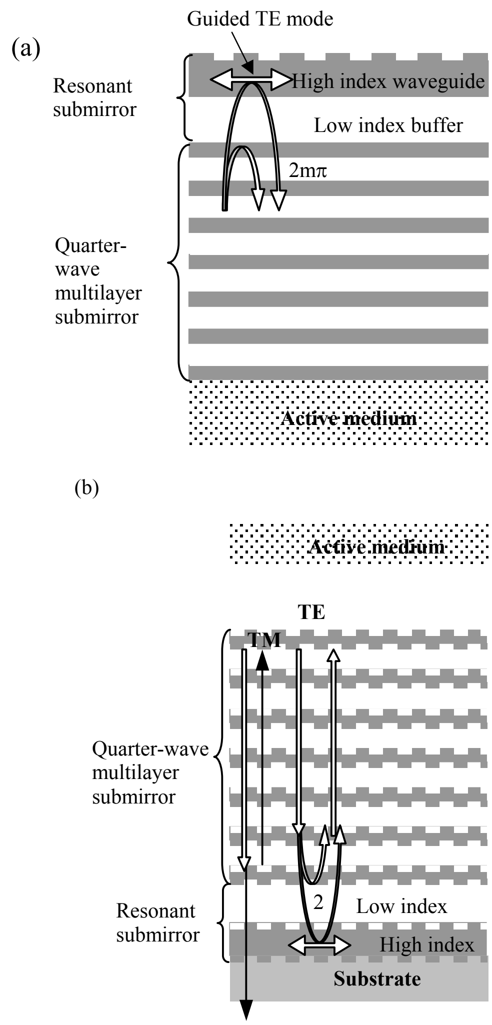

Fig. 1: (a) Operation principle of a polarizing mirror integrated to the active medium [2], (b) of a longitudinal mode filter. In both structures light experiences constructive interference between multilayer and resonant submirrors.

Figure 1a) is the sketch of the corresponding polarizing resonant mirror. The mirror in the present application is the stand alone rear mirror of an extended cavity laser. As a consequence, the reflection threshold provided by the very low loss multilayer submirror must be as high as possible, leaving only a few percents of reflection to the highly selective waveguide submirror, the only concern being that the spectral components outside the reflection peak do not lase. It must be looking at the inside of the laser cavity, its substrate being outside the cavity. Consequently, the resonant submirror must be located past the multilayer submirror on the way of the incident wave. This imposes the somewhat unusual configuration sketched in Figure 1b) where the mirror substrate gets first corrugated, then the resonant waveguide submirror layers are deposited as well as the layers of the multilayer submirror at once in the said order. It is important to point out that we are making use here of a resonant diffraction mechanism where the field in the waveguide is so large that a very shallow corrugation of hardly 15 nm depth is sufficient to give rise to high reflection. The layer deposition technology will be that of ion plating [4] which ensures a conformal reproduction of the corrugation amplitude up to a large number of layers.

The most important element in the multilayer system is the grating waveguide placed on top of the corrugated substrate. The whole synthesis of this element is made on the basis of the physical understanding of waveguide grating resonances first developed by Sychugov and team in the mid eighties [5]. The grating waveguide is well isolated from the multilayer by the thick low index buffer layer. It is symmetrical (double corrugation and cover and substrate index nearly identical). In addition, the waveguiding layer with its 240 nm thickness of Ta_2O_5 of 2.18 index is very close to a half wave layer. This implies that the modulus of resonant reflection shows as a single peak with zero offset and no side dip; as a consequence, the resonant reflection can be simply placed as a quasi symmetrical peak on top of the multilayer ground reflection. Fig. 2 shows that the transmission dip of the sole high index corrugated waveguiding layer surrounded by SiO_2 at both sides in the described conditions is symmetrical. The transmission falls from quasi 100% to zero as expected. The grating has a 559 nm period and a 21.6 nm deep sinusoidal corrugation. The transmission of the complete multilayer structure is represented by the dotted line of Fig. 2; it confirms that the two submirror reflections superpose constructively.

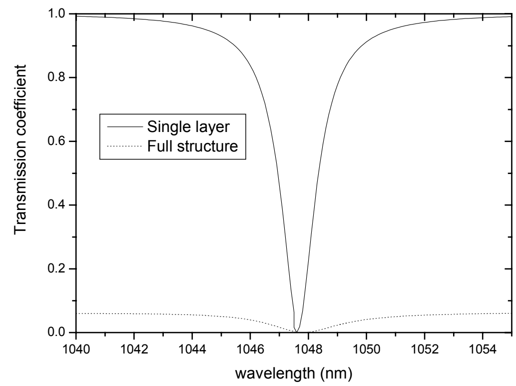

Fig. 2: Calculated transmission coefficient of the complete resonant mirror (doted line) and of the sole waveguide submirror (full line) versus wavelength in the resonance neighbourhood.

Figure 3 is the optimised reflection spectrum of the TE polarization, assuming plane wave incidence and infinite grating length; it extends to the green region because the mirror has the additional function of reflecting the second harmonics as well. The optimization was made by means of Lyndin's code using the C-method [6].

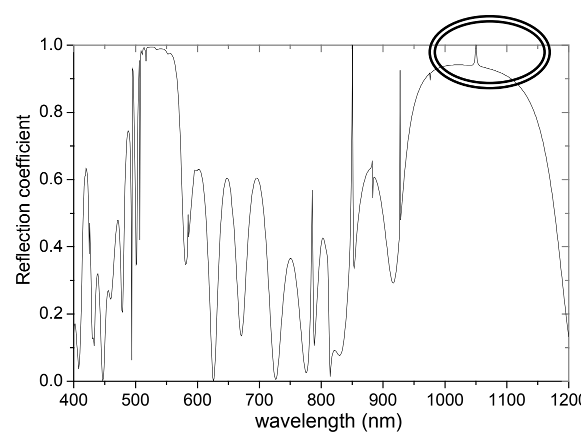

Fig. 3: Reflection coefficient of the optimised structure versus wavelength in the visible and IR regions with a peak at 1050 nm.

As shown in Fig. 4, the TE_0 waveguide mode field at resonance is well concentrated in the bottom high index layer.

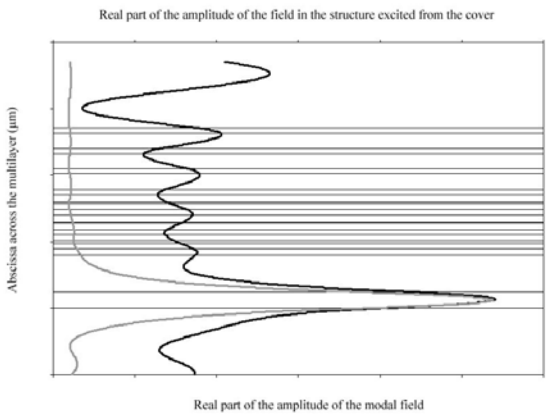

Fig. 4: Transverse electric field profile in the multilayer. Grey curve: TE_0 modal field, Black curve: field profile upon excitation from the air side. The horizontal lines show the different layers of the stack.

Experiment

The grating corrugation in the fused quartz substrate is obtained by first exposing a 300 nm thick positive resist layer to an interferogramme at the HeCd laser wavelength of 442 nm, then by reactive ion beam etching into the silica surface. The obtained depth is 17 nm. The multilayer is then deposited by ion plating [4]. The AFM scan of the surface after the deposition of the 2706 nm thick multilayer is also essentially binary with a depth of 23 nm.

Figure 5 is the spectral measurement of the TE polarized transmission of the complete structure around 1050 nm wavelength. It reveals under normal incidence a sharp and deep dip on a wide band transmission background. The measurements were made by using an optical fibre white light supercontinuum and a spectrometer of the type ANDO AQ-6315A Optical Spectrum analyzer ensuring a spectral resolution of 0.1 nm. The high spatial coherence of the source permits the separation between the angular and spectral effects. The beam diameter is about 1 mm. Index matching a prism at the backside of the grating substrate with glycerol (insert of Fig. 5), whose refractive index matches that of the silica substrate, reduces the oscillations due to the backside reflection and the resulting interference. This leads to the spectacular transmission spectra of figure 5 revealing that the TE line width is as small as 2.2 nm and that the transmission is practically cancelled. The transmission at resonance is two orders of magnitude below the off-resonance transmission. It is at the detection limit of the detector. Remarkable also is the fact that the resonance wavelength is only 1 nm away from the expected nominal resonance wavelength taking into account the experimental values of the grating period and depth in the calculations. This is a result of the good control which ion plating ensures on the layer index and thickness. The experimental transmission curve exhibits a double dip which infers that the incidence is not exactly normal. Experimentally, the autocollimation reference is defined at a resolution better than 0.02 degree. This is confirmed by calculating the theoretical transmission coefficient of the structure if illuminated under an incidence angle of 0.015°: the resulting spectrum (dashed curve in Figure 5) exhibits the same feature as the experimental curve with exactly the same 0.6 nm distance between the two dips. The line width under oblique incidence is proportional to the radiation coefficient α of the grating waveguide; in other words it scales as the square of the grating depth for small depths [7].

Figure 6 refers to a transmission measurement. Nothing presently tells that zero transmission amounts to exactly 100% reflection at resonance. Reflection measurements are very difficult to make with high precision. This will be the subject of further experimental studies.

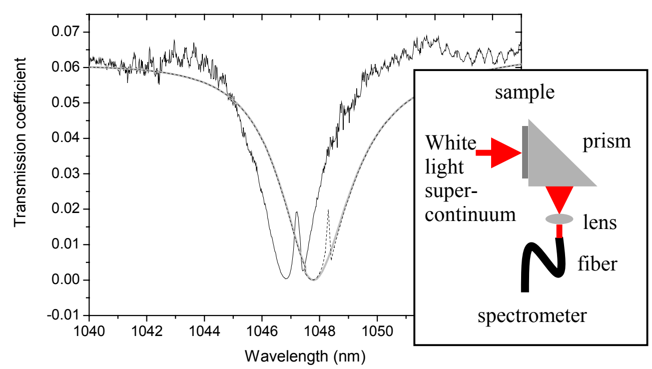

Fig. 5: Transmission coefficient of the structure around 1050 nm after suppression of backside reflection (insert). The grey curve is the theoretical transmission coefficient taking into account the measured grating parameters (period of 559.1 nm and depth of 17 nm). The dashed curve is the theoretical spectrum obtained under an incidence angle of 0.015°

Conclusion

The present paper reports on the demonstration of a further optical function that a waveguide grating can perform for laser control: line narrowing leading to longitudinal mode filtering. It is demonstrated that the constructive association between a broadband multilayer and a waveguide grating permits to fully benefit from the narrow filtering property of waveguide grating resonant reflection without the penalty of its absorption and scattering losses. The design of the resonant mirror is made via an intelligible synthesis process based on field diffraction and interference, only the optimisation step being left to numerical modelling. A line as narrow as 2 nm is obtained at 1050 nm wavelength for a beam of 400 nm diameter by an embedded binary grating of 17 nm depth. A remarkable feature is the achievement of practically zero transmission at resonance by means of a multilayer structure having all interfaces corrugated.

Acknowledgement

The authors want to thank J.Cl Pommier for performing the RIB-etching of the quartz grating and S. Reynaud for the AFM scans. This work is part of an initiative on resonant gratings within the European network of excellence on microoptics NEMO.

References

1. F. Pigeon et al., IEEE Photon.Technol. Lett., vol. 12, p. 648, 2000.
2. J.-F. Bisson et al., Appl. Phys. B, vol. 85, p. 519, 2006.
3. T. Moser et al., Laser Phys. Lett., vol. 1, p. 234, 2004.
4. S. Schlichtherle et al., Vakuum in Forschung und Praxis, vol. 17, p. 210, 2005.
5. G.A. Golubenko et al., Sov. J. Quantum Electron., vol. 15, p.886, 1985.
6. A.V. Tishchenko et al., Workshop on grating theory, Clermont-Ferrand, France, June 2004.
7. I.A. Avrutsky et al., J. Mod. Opt., vol. 36, p. 1527, 1989.