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STUTTGART LASER TECHNOLOGIES
Im Fokus

Generation of a 3 kW radially polarized beam from a CO_2 laser using an intracavity polarizing grating mirror

Axially symmetric (radially and azimuthally) polarized modes have shown an increasing interest within the last decades due to their several advantages for many applications like material processing, or for avoiding bifocusing due to the thermally induced birefringence in laser rods for instance.
For metal cutting, it has been theoretically predicted that radially polarized modes are preferable because of their higher absorption, in comparison to linearly or circularly polarized beams. In a micro-drilling process, it has been reported that azimuthally or radially polarized beams can, depending on the material used and on the process parameters, improve the drilling efficiency significantly in comparison to the generally used circular polarization.

Several techniques, using intra- or extracavity elements for the generation of radially and/or azimuthally polarized modes, have been developed and reported in the literature within the last years. Most of them are not well suited for high power applications because of their high losses and/or extremely high alignment sensitivity. We have therefore developed at the IFSW an intracavity, high power suitable, polarizing element which comprises, as shown in figure 1, a resonant grating with concentric grating lines etched in the top layer of a conventional standard multilayer mirror to generate a radially polarized beam in a CO_2 laser system. The principle of this polarizing grating mirror, which replaces the standard rear mirror, is based on the coupling of the incident free space beam to a leaky mode of the mirror's multilayer waveguide by the applied grating; the same principle is currently under investigation for high-power thin-disc lasers.

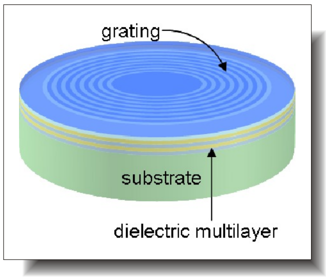

Fig. 1: Schematic 3D-view of the polarizing grating mirror with concentric grating lines.

The coupling of free-space radiation to waveguide modes caused by a grating is polarization selective since the phase matching condition can only be satisfied for one polarization at a time for a given angle of incidence and wavelength. In the case of leaky waveguides, the coupling is accompanied by a power leakage into the substrate. This loss mechanism leads to a reduction of the reflection coefficient for radiation with undesired polarization states in a laser resonator. Using such a mirror, either as the end reflector or as the output coupler in the resonator, leads to pronounced polarization selectivity. This monolithic approach contrasts with the GIRO monolithic mirror whereby the grating modes of a deep corrugation etched into a high index intracavity substrate interfere so as to ensure a close to 100% reflection of the desired polarization.

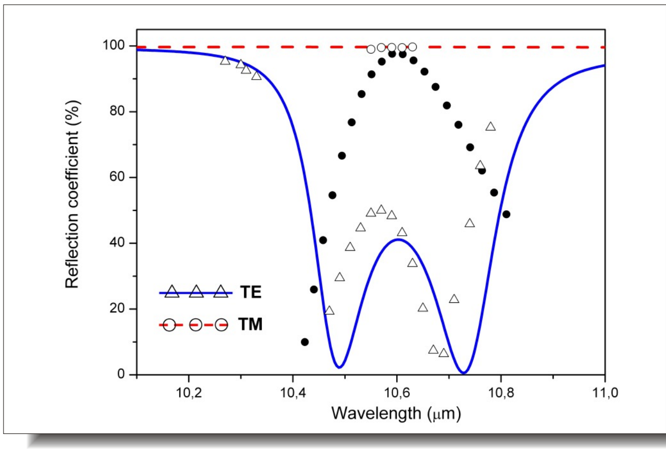

Fig. 2: Calculated (dashed and straight lines) and measured (open triangles and open circles) reflectivity spectra for radial and azimuthal polarisation for the 6.5 μm period and 200 nm groove depth grating under normal incidence. The dots represent the gain spectrum of the CO_2 laser.

The designed multilayer, in the present paper, is composed of Ge, ZnSe and ThF_4 layers deposited by II-VI Inc., USA. The grating was designed with a period of 6.5 μm and a groove depth of about 200 nm to couple the incident beam to two neighbouring leaky modes. This mode spectrum was designed and chosen in order to obtain a wide spectral bandwidth of the polarizing effect and therewith to widen the manufacturing tolerances of the structure parameters (thicknesses and refractive indices of the layers as well as groove depth, line to space ratio, and period of the grating). The solid and dashed lines in figure 2 show the calculated reflection coefficients for azimuthal and radial polarizations of the polarizing mirror as designed. The dots indicate the gain spectrum of the CO_2 laser. The calculated reflectivity for TE (which correspond to the azimuthal polarization on the circular grating) and TM (which correspond to the radial polarization on the circular grating) are 41% and 99.6% respectively. Without the grating, the multilayer mirror reflectivity is 99.8% for both polarizations. The calculations of the structures were carried out with the help of an exact modelling code based on the modal method. As a first step and for the spectral characterization of the polarizing effect, a linear grating has been fabricated. It was defined in a 1 μm thick positive photoresist layer by means of a mask transfer operation under vacuum to obtain a uniform contact between the chromium mask and the low curvature mirror substrate. The physical transfer was made by reactive

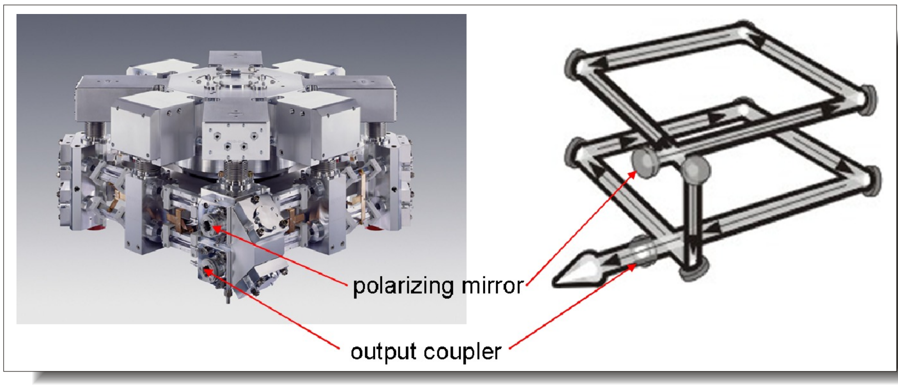

Fig. 3: CO_2 laser resonator used for the generation of the radially polarized beam.

ion beam etching of the last high index layer. The open triangles and open circles in figure 2 show the measured wavelength dependence of the reflectivity for the azimuthal and the radial polarizations respectively. The centre wavelengths of the two dips are shifted by about 50 nm to shorter wavelengths relative to the design; this may be due to some small differences between the parameters of the actual structure and the design. For example, the shift can be explained by a slightly reduced thickness of the coating layers; this difference is well within the manufacturing tolerances. Due to the large spectral width of the double dip, the shift does not affect the performance of the element. At a wavelength of 10.6 µm the reflectivity for the undesired TE (azimuthal) polarization is R_{azim} = 43.9% (± 0.3) % whereas it is R_{rad} = 99.5% (± 0.3) % for the wanted TM (radial) polarization. The measurements have been performed according to the DIN EN ISO 13697 with a slight modification for its use under normal incidence. After this confirmation of the proper behavior of the grating mirror a circular grating was fabricated in a second step using the same photolithography and etching process as for the linear grating.

For the intracavity laser tests, the polarizing mirror with the concentric circular grating was introduced in a TRUMPF TruFlow CO_2 laser shown in figure 3. Figure 4 shows a photograph of the generated pure doughnut-mode burned into a plexiglas cube. The polarization state over the beam cross section was verified by scanning the enlarged beam cross section using a LASNIX 605 apparatus with a rotating polarizer. The measured polarization distribution of the beam is depicted in figure 5. It clearly shows that the electrical field exhibits a pure radial distribution over the whole beam cross section. 3 kW of cw output power with a pure radially polarized mode were demonstrated using our grating mirror in the commercial laser system.

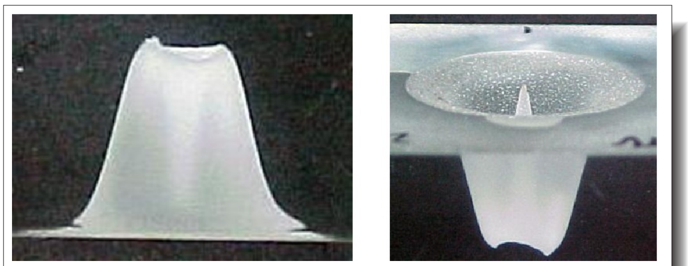

Fig. 4: Burn-in of the doughnut CO_2 laser beam into a plexiglas.

In a long-term test, the laser was operated at 2.7 kW cw output power with a stable and radially polarized beam for several hours. To our knowledge this is the highest stable and radially polarized beam power demonstrated to date. The efficiency of the laser with the radially polarized output in a pure doughnut-mode was measured to be 10 % lower as compared to the operation with the usual non-polarizing HR mirror. Considering that the spatial overlap of the pure doughnut-mode with the homogenous gain distribution of the laser is notably smaller than in standard laser configuration, this result is in a reasonable agreement to the expectations. In conclusion, the generation of up to 3 kW of cw power with a stable radially polarized beam from a commercial CO_2 laser by means of a resonant grating applied to the rear HR mirror of the laser cavity was demonstrated. Investigations on the applications of radially and azimuthally polarized high-power laser beams are under progress and will be reported on at a later date.

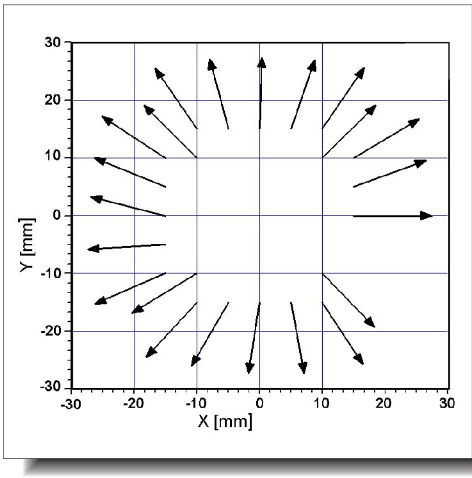

Fig. 5: Measured Polarization distribution over the beam cross section. The arrows show the polarization direction through the LASNIX 605 apparatus at different positions over the beam cross section.

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