Efficient conversion to radial polarisation in the two-micron band using a continuously space-variant half-wave plate

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Radially and azimuthally polarised beams have attracted growing interest for use in a variety of applications due to their unique optical properties. The most popular way to obtain these beams at relatively low power levels is to transform a linearly-polarised TEM_{00} beam into a radially or azimuthally-polarised beam using an external polarisation mode converter. Traditionally, these converters were contructed from an arrangement of half-wave plated bonded together to form a segmented spatially-variant retardation plate (SVR) [1] and, as a consequence, they generally suffered from low polarisation purity, degraded beam quality and low transformation efficiency. However, recent work on femtosecond laser writing of nanostructure gratings in silica glass has allowed the realization of a new type of radial polarisation converter with improved performance. In these converters the grating structures induce birefringence with slow and fast axes aligned parallel and perperdicular to the grating direction respectively, which is aligned at an angle $\varphi/2$ from the azimuthal angle φ to form a continuously space-variant half-wave plate (S-waveplate) [2]. S-waveplates provide dramatically improved polarization purity compared to segmented retardation plates, but do have the shortcoming of a rather high scattering loss induced by microscopic inhomogeneities of nanogratings, which is strongly dependent on wavelength.

In this paper, we report on an S-waveplate designed for use in ~2µm wavelength band with high polarization purity and very low scattering loss. The S-waveplate was fabricated in-house by femtosecond laser writing in a silica window and was tested with the aid of a probe beam from a widely-tunable Tm-doped silica fibre laser. The latter produced a nearly diffraction-limited (Gaussian-shaped) beam with a beam propagation factor (M^2) of 1.2 and could be tuned over the wavelength range from 1950nm to 2100nm with an output power of 1.5W. The output from the fibre laser was polarised using an external polariser to yield a linearly-polarised beam with a polarisation extinction ratio (PER) ~ 22dB and the S-waveleplate was aligned with respect to the incident beam polarisation direction to yield a radially-polarised output beam. The resulting doughnut-shaped far-field beam profile was observed with the aid of a Pyrocam III camera (see Fig.1(a)). The far-field beam profile after passage through a rotated polariser is illustred in Fig. 1(b)-(e) verifying that the polarization is indeed radial. The transmission efficiency was measured to ~86.2%±1.5% across the wavelength tuning range. Taking into account the Fresnel reflection losses on both uncoated surfaces, this suggests a single-pass loss due to scattering of less than 0.07, which is considerably smaller than the scattering loss of ~0.2 measured for an S-waveplate intended for use as a radial polarisation converter in the ~1µm wavelength band.

The M^2 factor was measured to be ~2.1 and hence in close agreement with the theory confirming the high quality of radially-polarized doughnut beam generated by the S-waveplate. The PER was investiaged by measuring the intensity of the two-lobed beam at a specific radius as a function of azimuthal angle (as illustrated in Fig. 1(f)). The PER of beam is defined as the averaged ratio of I_{max}/I_{min} for the four two-lobed beams in Fig. 1(b)-(e). With this method, the PER was calculated to be ~ 15.5dB. It is worth mentioning that the value of PER varies by less than 3dB from 1950nm to 2100nm with a maximum PER of 17.5dB at 2050nm. This shows that the S-waveplate is a very effective radial polarisation converted across a wide wavelength band. These results for performance of the S-waveplate suggest that it would be suitable for use with high average power lasers at 2µm. The prospects for further improvement in performance of S-waveplate and a further improvement in overall transmission will be discuseed.

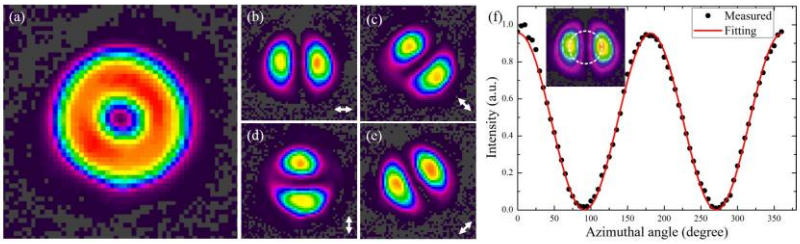

Fig. 1 Experimental far-field intensity distribution ; (b-e)beam profiles after passage through a rotated linear polariser. The white arrows indicate the transmission direction of polariser. (f) PER measurement.

References

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