Xiao, Q., Klitis, C. , Chen, H., Li, S., Chen, Y., Zhu, J., Cai, X., Sorel, M. and Yu, S. (2016) A Coaxially Integrated Photonic Orbital Angular Momentum Beam Multiplexer. In: IEEE 13th International Conference on Group IV Photonics (GFP 2016), Shanghai, China, 24-26 Aug 2016, pp. 114-115. ISBN 9781509019038 (doi:10.1109/GROUP4.2016.7739121)

A coaxially integrated photonic orbital angular momentum beam multiplexer

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Abstract: We demonstrate an integrated photonic orbital angular momentum beam multiplexer consisting of four nested arc waveguide gratings. Well-defined OAM mode emissions over wide bandwidth of 1-nm enables simultaneous wavelength division multiplexing and OAM multiplexing.

1. Introduction

Orbital angular momentum (OAM) of photons [1] is highly attractive for applications in diverse fields such as classical [2] and quantum information systems [3] and particle trapping and manipulation [4]. Recently, several compact Photonic Integrated Circuits (PIC) devices for the generation of optical vortices carrying OAM [5,6] have been proposed. Amongst them, the micro-ring emitter provides a compact solution to efficiently achieve well defined and easily tuned [7] topological charge. However, the resonant micro-ring cavity imposes one-to-one correspondence between the topological charge and the optical wavelength (or frequency), and its enclosed structure post challenges for constructing coaxial emitters - not conducive to the use of OAM and wavelength multiplexing. Here, we report a Ω-shaped OAM-beam multiplexer formed by coaxially nesting arc waveguide gratings.

2. Basic concept and device design

The arc grating OAM-beam emitter stems from the micro-ring OAM emitter [5] by opening a gap on the ring with a notch angle of α, as schematically shown in Fig. 1(a). The arc section has radius R and arc angle $2\pi-\alpha$, and angular gratings azimuthally distributed along the arc inner circumference with period $\Lambda=(2\pi-\alpha)R/q$, where q is the grating number. These angular gratings scatter waveguide mode into free-space emission carrying orbital angular momentum, similar to those reported in [5].

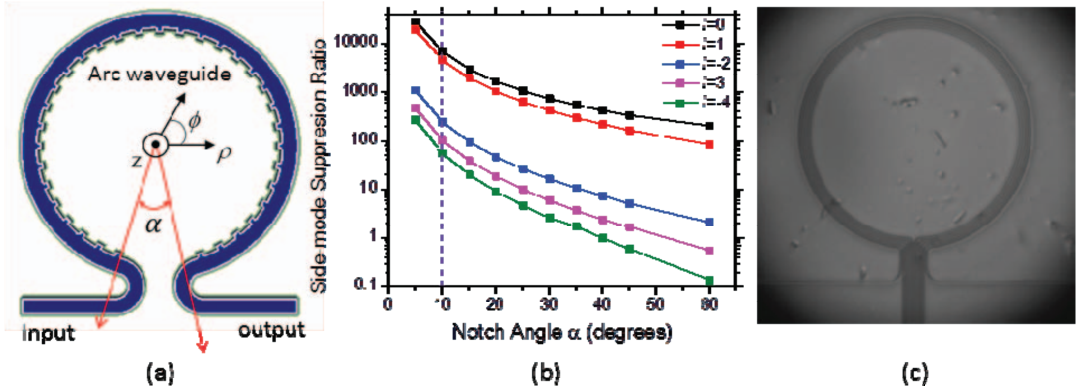


Fig.1 The concept and design of Ω-shaped OAM-beam emitter. (a) Schematic of Ω-shaped emitter; (b) The relationship between SMSR and notch angle α for different major OAM orders ; (c) Micrograph of the Ω-shaped OAM multiplexer.

The angular phase-matching condition dictates that radiated field has topological charge of $l=(2\pi-\alpha)R(n_{\mathrm{eff}}/\lambda-1/\Lambda)$, where λ is the free space wavelength and n_{eff} is the effective refractive index of the bend waveguide. **When** α=0, this phase-matching condition is identical to that in the micro-ring OAM emitter [5]. For wavelengths λ_r fulfilling $2\pi R n_{\mathrm{eff}}=p\lambda_r$, integer l will be maintained. However, as there is no resonance constraint, input wavelengths between λ_r values are allowed and non-integer l values or fractional OAM states will be emitted.

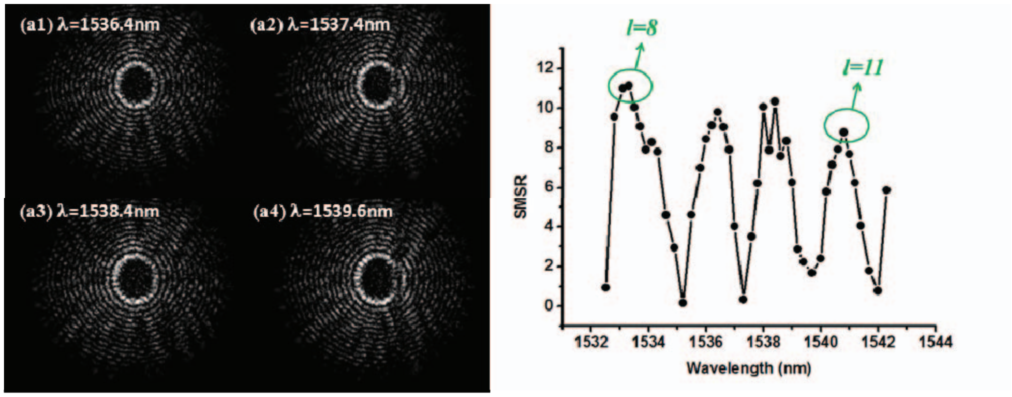
However, at λ_r, the missing near field in the notch angle α also reduces the mode purity. Figure 1(b) shows the SMSR (Side Mode Suppression Ratio, defined as the power of the dominant mode divided by that of the second highest mode) as a function of the angle α at different dominant topological charge, which is calculated using the dipole model [8]. Clearly SMSR deteriorates as the notch angle increases. For the same notch angle, higher order OAM suffers lower SMSR. If we set the OAM mode purity criteria to be SMSR>20 dB and aim at an emitter supporting $l=-3$ to +3 modes, the notch angle should be limited to within 10°.

3. Experimental results

The opening notch in the waveguide allows Ω-shaped emitters with different arc radii to be nested coaxially as in Fig. 1(c), resulting in an 8-OAM multiplexer by integrating four Ω-shaped devices.

Several far-field patterns from an Ω-shaped OAM-beam emitter with R=37.56 μm are shown in Fig. 2(a). The wavelengths for Fig. 2(a1) and 2(a3) are very close to wavelengths λ_r and the far filed patterns are rotationally symmetric similar to those from the micro-ring emitters. While away from a λ_r, Fig. 2(a2) and 2(a4), the far field patterns have dark-lines [9] along the radius that break the rotational symmetry, indicating fractional OAM.

To characterize the performance of the Ω-shaped OAM-beam emitter, a SLM-based OAM spectrum analysis system [10] is used to evaluate the SMSR as a function of wavelength. As shown in Fig. 2(b), SMSR peaks analogous to resonance spectrum in micro-ring resonators have been obtained. SMSR of >10 dB can be achieved at the λ_r wavelengths, while dropping down to 0-dB in between, where two equally weighted modes would be emitted. A wavelength range about 1 nm within which SMSR maintains a reasonable value (1~2 dB down from maximum) can be achieved, sufficiently wide-band for the OAM multiplexing applications.



(a) (b)

Fig.2 (a) far-fields captured at the wavelengths very close to the corresponding resonant wavelengths (a1,a3) and far away from the corresponding resonant wavelengths (a2,a4); (b) The measured SMSR of the Ω-shaped OAM-beam emitter as a function of wavelength.

4. Conclusions

An Ω-shaped OAM-beam emitter have been demonstrated that emits well-defined OAM modes with >10-dB SMSR over bandwidth of 1-nm. The opening arc structure enables coaxial integration of multiple OAM emitters for simultaneous wavelength division multiplexing (WDM) and OAM multiplexing.

5. Acknowledgements

The authors acknowledge funding from the China National 973 Project 2014Cb340000, NSFC project 61490715, and the EU H2020 project ROAM.

6. References

[1] L. Allen, et al, Phys. Rev. A **45**(11), 8185–8189 (1992).
[2] J. Wang, et al, Nat. Photonics, **6** (7), 488–496, (2012).
[3] A. C. Dada, et al, Nat. Phys., **7**(9), 677–680(2011).
[4] M. Chen, et al, Opt. Lett., **38**, (22), 4919-4922(2013).
[5] X. Cai, et al, Science **338** (6105), 363–366 (2012).
[6] N. K. Fontaine, et al, paper OTu1I.2, Optical Fiber Communication Conference 2012.
[7] M. J. Strain, et al, Nat. Commun. **5**, 4856 (2014).
[8] J. Zhu, et al, Optics Lett., **38**(8), 1343-1345(2013).
[9] J. Leach, et al, New J.Phys.**6**, 71 (2004).
[10] Q. Xiao, et al, Optics Express, **24**(4),3168 – 3176(2016).