Experimental Observation of Optical Bistability in an Integrated Vortex Beam Emitter

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Abstract—**We experimentally demonstrate an interesting phenomenon of optical bistability in an integrated optical vortex emitter when injecting high power into the waveguide due to the nonlinear optical effects. We clearly observe a hysteresis loop of the radiation power from the integrated vortex beam emitter when increasing and decreasing the input power.**

Keywords-optical bistability; nonlinear optical effects; optical vortex; micro-ring resonator

I. INTRODUCTION

Optical vortices are light beams with a singularity at the beam center, either polarization singularity (vector beams) or phase singularity (orbital angular momentum (OAM)) [1]. In the past decades, optical vortex beams have seen wide-ranging applications in optical manipulation, optical trapping, optical spanner, optical vortex knots, microscopy, imaging, quantum information process and optical communications [2-5]. First and foremost, a device generating optical vortices is highly desired to enable these applications. Compact, robust, and efficient planar waveguide–based vortex emitters and receivers are critical elements, as they can be integrated in large scales and interconnected via waveguides with each other and with lasers and detectors to form photonic integrated circuits (PICs). There are many kinds of waveguide-based devices to generate optical vortices, one of which is to embed angular grating structures into the whispering gallery mode (WGM) resonator with a periodic modulation of refractive index in the azimuthal direction [6]. Meanwhile, optical bistability has been demonstrated theoretically and experimentally in various photonic devices with nonlinear responses and feedbacks, such as Fabry-Perot resonators, fiber Bragg gratings, photonic crystal micro-cavities and microring resonators [7-9], etc. In systems that display optical bistability, the outgoing intensity is a strong nonlinear function of the input intensity, and might even display a hysteresis loop. The phenomenon of optical bistability has attracted a large interest in photonics since it enables the full optical implementation of switches, logical gates, and memories [10]. Thus, the integrated photonic devices generating optical vortices may feature optical bistability which may develop new applications in optical vortex based network, such as all optical vortex switch, transistors, logical gates, and memory. In this paper, we demonstrate optical bistability in a vortex beam emitter. We experimentally demonstrate the phenomenon of optical bistability in the vortex emitter when injecting high power into the waveguide due to the nonlinear optical effects. We observe the bistability in the integrated vortex emitter by measuring the radiation power as function of the input power. By increasing and decreasing the input power, the radiation power displays a hysteresis loop.

II. CONCEPT AND PRINCIPLE

The operation principle of the integrated optical vortex beam emitter is to couple the rotating WGM in the micro-ring resonator to a vertically propagating vortex beam assisted by embedded angular gratings. By matching the wavelength of the light with the micro-ring resonance, and by detuning it from the grating Bragg wavelength, the integrated device (i.e. micro-ring resonator with embedded angular grating structures) is capable of emitting a propagating field of desired vortex topological

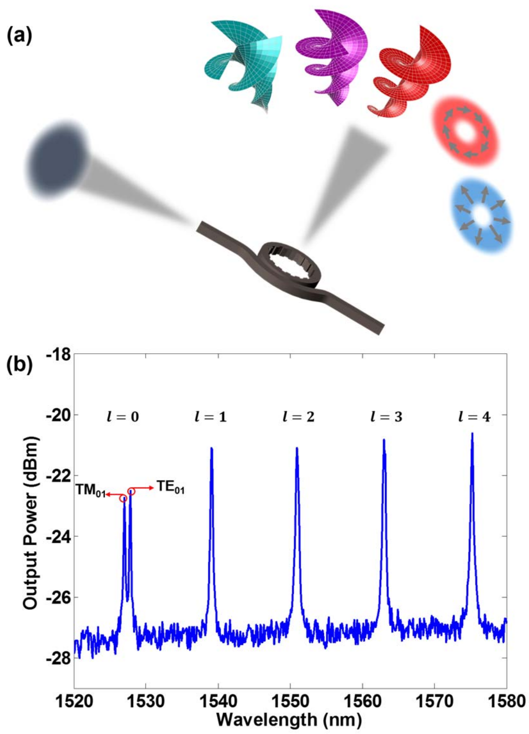

Figure 1. (a) Concept and principle of the integrated device generating optical vortices. (b) Measured radiation spectra of the integrated vortex emitter.

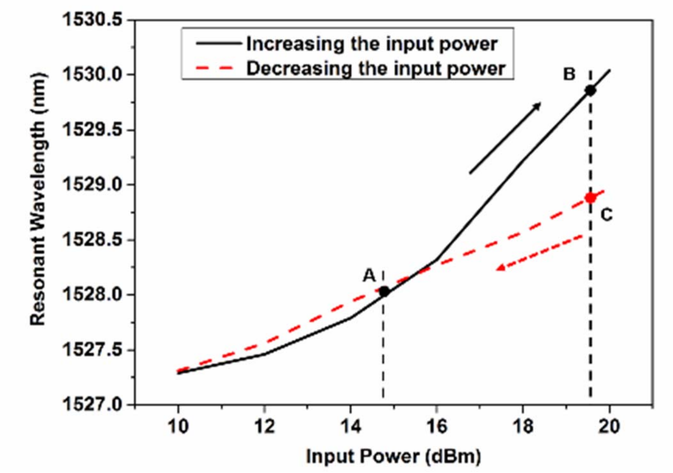

Figure 2. Measured resonant wavelength versus input power.

charge l. Fig. 1(a) shows the concept of the integrated device generating optical vortices. In the experiment, a polarization controller (PC) is placed at the input of the waveguide which is used to launch light in the quasi-TE mode before coupling the light into the input waveguide of the micro-ring resonator, and the power is monitored by a power meter placed at the output port of the waveguide. The radiation power is measured by a free space power meter after being collimated by an objective lens. The measured radiation spectra of the integrated vortex emitter by scanning the input laser wavelength is shown in Fig. 1(b). At l =0, there is a mode splitting due to strong cross-coupling between the otherwise degenerate clockwise and counter-clockwise travelling waves in the micro-ring, caused by the Bragg reflection of the grating. It is found that the shorter and longer wavelength resonances of this splitting mode are associated with radially and azimuthally polarized beams (TM_{01} and TE_{01}), respectively.

III. Experimental results

First, we measure the resonant wavelength of TM_{01} mode as a function of the input power. We first measure the resonant wavelength by increasing the input power point by point from 10 dBm to 20 dBm which is plotted in Fig. 2 in black solid line.

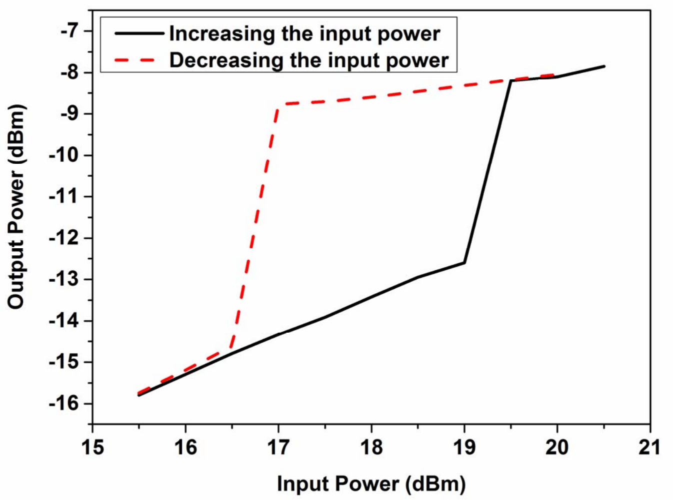

Figure 3. Measured radiation power versus input power when the wavelength is fixed at 1529.57 nm. A hysteresis loop is observed.

Then we measure the resonant wavelength by decreasing the input power from 20 dBm to 10 dBm which is plotted in Fig. 2 in red dotted line. By comparing the two lines in Fig. 2, one can find the linearity range and nonlinearity range of the vortex emitter. When the input power is lower than 15.8 dBm (point A in Fig. 2), the vortex emitter works linearly. Otherwise, it works in the nonlinearity range (points B and C in Fig. 2). The slight difference of resonant wavelength when the input power is lower than 15.8 dBm might be caused by the uncertainty of the measurements or fluctuation of environment temperature.

We further measure the radiation power as a function of the input power when the vortex emitter works in the nonlinearity range as shown in Fig. 3. The laser wavelength is fixed at 1529.57 nm in Fig. 3 taken from point B in Fig. 2. We measure the radiation power by increasing and decreasing the input power between 15.5 dBm and 20.5 dBm shown as black solid line and red dotted line respectively. The measured two lines form a hysteresis loop which clearly confirms the optical bistability phenomenon in an integrated optical vortex emitter when working in the nonlinearity range.

In conclusion, we experimentally demonstrate the phenomenon of optical bistability in an integrated vortex beam emitter when injecting high power into the waveguide due to the nonlinear optical effects. We observe the bistability of the vortex emitter by measuring the radiation power as a function of the input power. By increasing and decreasing the input power, the radiation power displays a hysteresis loop, indicating the bistability.

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