Degenerate cavity supporting many Laguerre-Gaussian modes

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Abstract: We have constructed two kinds of degenerate cavities that support many Laguerre-Gaussian (LG) modes with well-defined orbital angular momenta (OAM). The cavity with four lenses and four mirrors was shown to support 31 LG modes; while the cavity constructed by four spherical mirrors was shown to support more than 46 LG modes. Our experimental results establish the critical techniques to manipulate multiple OAM degrees of freedom, which are useful for quantum simulation.

Photons propagating in Laguerre-Gaussian (LG) modes have characteristic orbital angular momenta (OAM) [1], which are fundamental optical degrees of freedom. Recently, OAMs are treated as sites in a physical chain and coupled degenerate resonators supporting different OAM modes are proposed to quantum simulate two-dimensional topological physics [2]. By introducing more elaborate manipulations on OAMs in resonators, all optical quantum devices can be realized [3]. However, all such potentially novel applications are ascribed to set up a kind of degenerate optical cavity, which can support many energy-degenerated OAM states.

The theoretical framework of a degenerate cavity has been investigated in 1969 [4]. The resonant frequency for each LG mode with parameters p and l in a ring-type cavity is determined as

$$kL_0 - (2p + |l| + 1)\cos^{-1}\frac{A+D}{2} = 2n\pi, \qquad (1)$$

where n is an integer and L_0 is the length of the round-trip optical path. A and D are parameters of the ABCD matrix of the cavity. When $A + D = 2$, the resonant frequency is independent of parameters p and l, which means the cavity is degenerate for spatial modes. We first constructed a degenerate cavity with four lenses and four mirrors [5]. The transmission peaks of different input modes are measured. We found that more than 21 LG modes are degenerate within the 12 MHz bandwidth of the cavity.
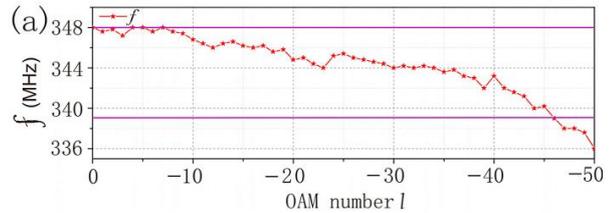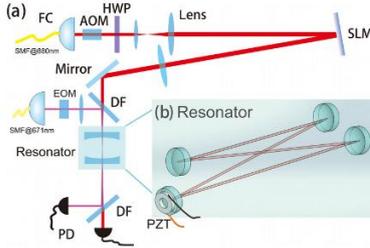

Fig. 1: Experimental setup for the cavity with four spherical mirrors.   Fig. 2: The resonant frequency of different modes

In order to further increase the number of LG modes resonant in the degenerate cavity and simplify the experimental setup, we considered to use spherical mirrors to construct the cavity [6], which is shown in Fig. 1. The dispersion of the resonant frequencies of different modes is shown in Fig. 2. We obtained more than 46 LG modes degenerated in the cavity with a bandwidth of 9.4 MHz. Our work represent the first experimental work demonstrating the degenerate cavity supporting many LG modes, which open the way to manipulate the synthetic degrees of freedom for OAM states.

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