Supplementary file: Superior ultrafast laser inscribed photonic-lantern mode (de)multiplexer using trajectory-asymmetry with uniform waveguides

1. Simulations for mode evolution simulation of the photonic-lantern mode multiplexer

The mode evolution simulation of the device using trajectory-asymmetry with uniform waveguides is shown in Fig. S1. Three waveguides have the same waveguide size. The spacing between the center of the waveguide on both sides is set here as d. When the waveguides are far enough apart, they are independent and excite single-mode light spots. As the three waveguides gradually approach, mutual coupling occurs between the waveguides. Due to the asymmetry of the structure, the modes of the light beam evolution from different waveguides are different. Finally, the middle waveguide gradually changes to a Gaussian single-mode mode, and the modes of the other two waveguides evolve into LP modes that mirror each other. Therefore, selective excitation and multiplexing of three LP modes were achieved through the device using trajectory-asymmetry with uniform waveguides. From the simulation results, it can be seen that the mode evolution from the input of the two waveguides on both sides happens to exhibit a mirror distribution. Therefore, two LP modes, one with a positive 45° distribution and the other with a negative 45° distribution, appear to have undergone a 90 ° mode rotation.

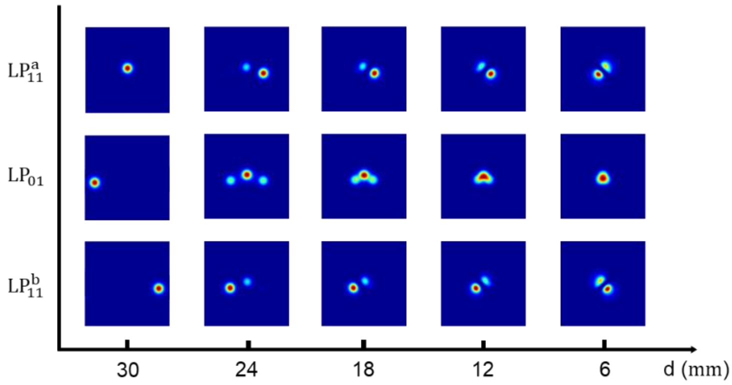

Fig. S1. Simulations for mode evolution simulation of the photonic-lantern mode multiplexer

2. Experimental results for parameter optimization process of the photonic-lantern mode multiplexer

The photonic-lantern mode multiplexers with bending waveguide lengths ranging from 7.5 mm to 11 mm are fabricated. The measured output beam intensity profiles of the mode multiplexers are shown in Fig. S2. From the experimental results, it can be seen that high-quality LP mode excitation can only be achieved when the coupling length is appropriate. The channel of $\boldsymbol{LP_{01}}$ mode always maintains excellent mode excitation. For the channel of LP_{11}^a mode, it has better mode excitation when the waveguide bending length is between 8.5 mm and 9.5 mm, while the channel of LP_{11}^b mode has better mode excitation at 9 mm to 10 mm. Considering that the waveguide fabricated first will actually have a certain impact on the waveguide fabricated later, the actual device obtained is not perfectly mirror symmetric, resulting in slightly different mode coupling lengths required for two LP_{11} modes. In order to further determine more accurate device parameters, a series of devices were fabricated with a difference of 0.1 mm spacing within the above waveguide bending range. Although the difference is small, the insertion loss performance was best measured when the length of the bent waveguide corresponding to LP11a mode was 8.9 mm and the length of the bent waveguide corresponding to LP11b mode was 9.7 mm. Therefore, this article mainly presents the data results of the device.

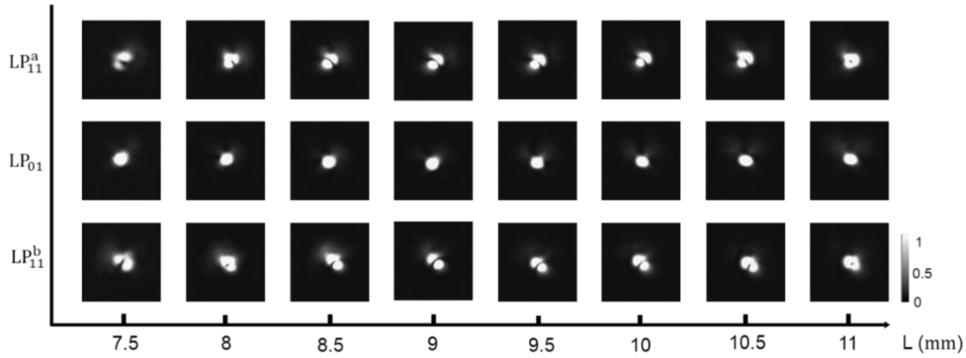

Fig. S2. The measured output beam intensity profiles of the mode multiplexers with bending waveguide lengths ranging from 7.5 mm to 11 mm