The Chiral Nanophotonic Coupling in Two Crossed Fibers

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Abstract- **In this paper, we demonstrate and investigate numerically the chiral coupling effect between a microfiber and a nanofiber. The light propagation direction in the nanofiber is determined by the handedness of the light field in microfiber. According to the radius of nanofiber, the fundamental mode in microfiber can be coupled into both the fundamental and the higher order modes of nanofiber. Our findings have potential applications in new designs of nanophotonic devices.**

Keywords—Chiral coupling; spin-direction locking; nano-photonic device

I. INTRODUCTION

The chiral coupling emerges naturally in nanophotonic structures such as waveguides and optical nanofibers, where the evanescent wave emerges [1]. In the evanescent electromagnetic wave, the spin-direction is inherently locked, i.e., the direction of phase propagation is fundamentally locked with the transverse spin of the wave [1]. Based on this phenomenon, chiral nanophotonic waveguide [2], chiral photon-emitter [3], and quantum optical circulator [4] have been demonstrated. It is interesting to investigate chiral coupling effect between two crossed MNFs.

II. PHYSICAL MODELS

As shown by Fig. 1(a), a nanofiber and a microfiber is cross-connected. A neared laser beam is injected into MF along the +*x* direction. Since the diameter of the MF is only 1000nm, evanescent wave emerges outside the fiber. The evanescent wave will be scattered by the NF, which will excite modes in NF. The scattered power of NF is

$$I^{\pm}_{scat} \propto \left|\alpha \cdot \mathrm{E}^{*}_{MF} \cdot \mathrm{E}^{\pm}_{NF}\right| \tag{1}$$

where α denotes the coupling strength. $\mathbf{E}_{MF} = a\mathbf{E}^{TE}_{MF} + b\mathbf{E}^{TM}_{MF}$ is the electric field MF, with a and b being the complex amplitude of TE and TM modes. $\mathbf{E}^{\pm}_{NF}$ represents the light field in NF, with ± denoting the propagation directions along $\pm z$ of NF. The foundational and higher-orders modes can be excited in NF. As shown by Mechelen and Jacob [1], the x and y field components of foundational mode will form a transverse spin $\hat{\boldsymbol{S}}$, which is along azimuthal or anti-azimuthal direction. Therefore, the spin $\hat{\boldsymbol{S}}$ is along $\pm x$ direction at the connected point. The spin direction is locked to the direction of phase propagation $\boldsymbol{\kappa}$ in nanofiber. As shown the inset in Fig.1(a), for $+x$ transverse spin, propagation direction is along $+z$, sign($\boldsymbol{\kappa}$) = +1 while it is along -z direction for $-x$ transverse spin, sign($\boldsymbol{\kappa}$) = -1. It is interesting to noted that the transverse spin of NF at the connected point $\hat{\boldsymbol{S}}_x$ coincides with the longitudinal spin of MF. Therefore, if the light field in MF is right/left handed polarized, the $\pm x$ transverse spin will be excited, resulting in power propagating along ±z directions, respectively. The directional coupling phenomenon is clearly seen in Fig. 1(b), where the light field in MF is right handed circularly polarized.

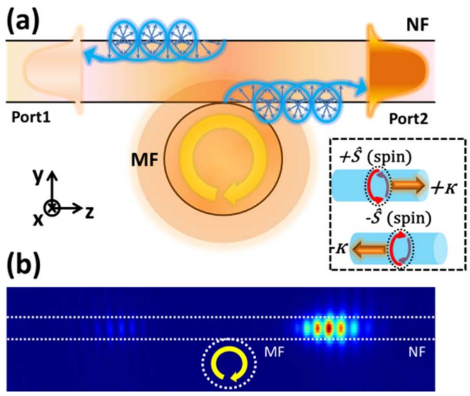

Fig.1. The schematic of chiral nanophotonic coupling a microfiber and a nanofiber.

III. RESULTS AND DISCUSSIONS

In this paper, we investigate the chiral coupling effect by using the finite-difference time-domain (FDTD) method (Luminal Int.). The radius of MF is fixed 500*nm* in the simulation.

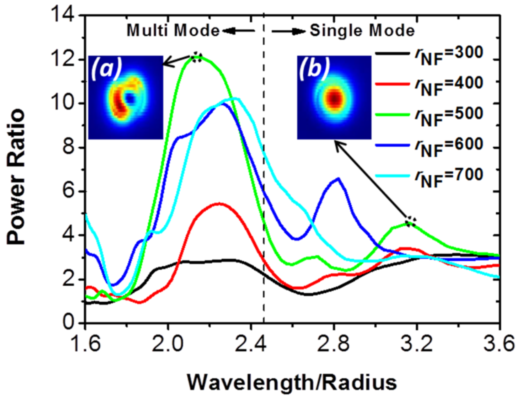

Fig.2. The dependence of power ratio on the normalized wavelength λ/r for different radii of NF. The radius of MF is fixed 500*nm*.

Figure 2 shows the dependences of power ratios between port 2 and port 1 of NF on the normalized wavelength λ/r for different NF radii, where the wavelength has been normalized by the radius of NF. The power ratios vary with the normalized wavelength, and two main peaks can be found between 1.6 and 3.6, for a NF with different radii. The two peaks correspond respectively to the foundational and higher-order modes, which is evident in insets (a) and (b), where the intensity distributions are shown for λ/d= 2.12 and 3.16, respectively. The power ratios are higher for the cases of higher-order modes. For each NF, the highest NF are obtained around λ/d =2.12. Among all the NFs, the highest ratio is about 12:1, which is obtained when the radius of NF is 500*nm*.

To investigate the dependence of the directional coupling on the polarization state in MF, we generate several kinds of polarization by adjusting the phase and amplitude of fundamental TE and TM modes of MF. The radii of both the NF and MF are 500*nm*. The modeled results are shown in Fig. 3, where $t=a/b$, denoting the amplitude ratio between TE and TM modes. $t=\pm i$ correspond to the right and left handed circular polarizations. When the handedness of the polarization state in MF change, the power ratio (in dB) changes signs. The power ratios are higher for $t=\pm i$ than the other cases, since the longitudinal spin in MF are matching better with the transverse spin in NF.

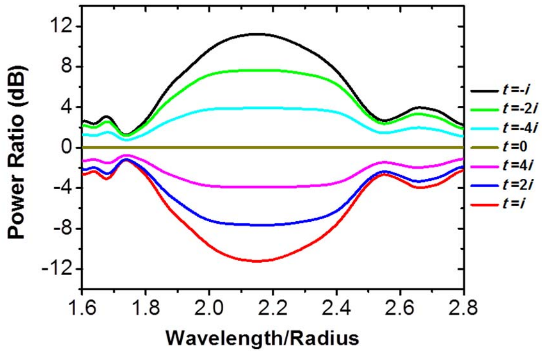

Fig.3. The dependence of power ratio on the normalized wavelength λ/r for different the polarization states of MF.

IV. CONCLUSIONS

Through the numerically investigation, we have proposed a simple structure to realize a chiral coupling effect. It is found that the propagation direction of light field in the NF is determined by the handedness of the light field in MF. The power ratio between two output ports of NF is up to 12:1. The ratio can be further increased by optimizing the radius of MF. We believe our findings have potential applications in the design of nanophtonic devices.

V. ACKNOWLEDGEMENTS

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