Numerical Design and Characterization of a Micro/Nano-Fiber Based Polarization Beam Splitter

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***Abstract*—The polarization splitting characteristics of a polarization beam splitter (PBS) based on two closely spaced parallel optical micro/nano-fibers (MNFs) were studied using the three dimension full vector beam propagation method (3-D FVBPM). Our results of the study show that a very compact PBS can be realized. Through numerical simulation, the geometric parameters of the PBS were optimally selected to ensure desired polarization splitting performance. Additionally, the fabrication tolerances of the device were also studied.**

Keywords—Micro/nano optical fiber ; polarization beam splitter ; 3D full vector beam propagation method ; polarization extinction ratio ; numerical simulation

I. INTRODUCTION

Polarization beam splitters (PBSs) are widely used in optical switching networks, optical storage and image processing. The evanescent-field coupling characteristics of MNF based couplers have been studied [1][2][3].

In this work, a PBS based on evanescently coupled cylindrical MNF is designed and optimized using 3-D full vector beam propagation method (3-D FVBPM). The BPM simulations are performed using a commercially available software package, Rsoft-Beamprop. The diameter and the gap distance of two parallel MNFs are optimized to yield the shortest coupling length. Our simulations show that the optimized PBS can achieve good TE and TM polarization splitting. We believe that this study will benefit the development of optical devices with ultra high level integration capabilities.

The physical model of our PBS, shown in Fig. 1, consists of an input waveguide, an evanescent coupling region, and two bent output waveguides. For simplicity, in our numerical simulation, we have treated both MNFs as a cylindrical fiber core with air as cladding. Meanwhile, we assume that the sidewall of the MNF is intrinsically smooth, so that any scattering induced by sidewall roughness is negligible [1]. According to mode coupling theory [4], a maximum coupling efficiency can be obtained between two identical MNFs having matched propagation constants. Therefore, our PBS design is based on two identical silica MNFs and our simulation is focused on figuring out the optimal MNF diameter D, optimal coupling distance Lc and gap distance G of coupling zone, distance H between two output fiber ends, as shown in Fig. 1, since these parameters play the most important role in achieving the best performance of such a PBS.

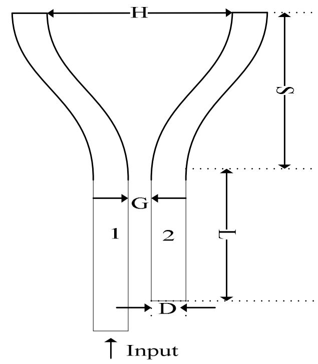
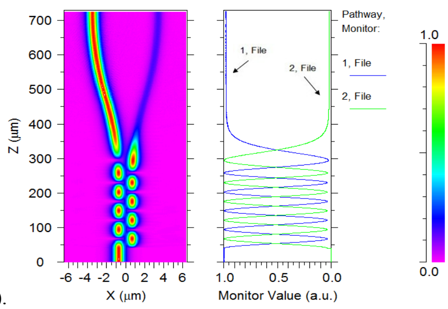


Fig. 1. The model of the polarization beam splitter (PBS).

II. NUMERICAL SIMULATION AND PERFORMANCE ANALYSIS

a).



b).

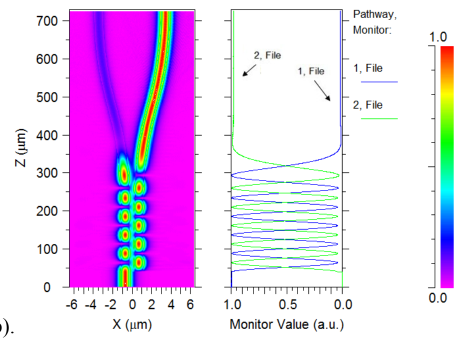


Fig. 2. a).The TM mode output in the left port of PBS ;b).The TE mode output in the left port of PBS.

Using the Rsoft-Beamprop software, we launched a linearly polarized input beam at a 45° polarization angle relative to the x-axis and calculated the output mode field distribution using our finally selected optimal PBS geometric parameters, The result is shown in Fig.2, in which Ex and Ey represent respectively the x and y component of the transverse mode. It can be seen that the x component (TE polarization) emerges from output port 2 and the y component (TM polarization) emerges from output port 1. Both the normalized power of TE and TM mode oscillate periodically in sine within the coupling length. When the coupled fiber length is greater than 450*μm*, the output power becomes stable. It indicates that polarize beam splits is achievable and the total fiber length of PBS should be 450*μm* at least.

With the fiber diameter *D* of *0.9μm*, the fiber refractive index of *1.46*, the background index of *1.0*, and *G* of *0.5μm*, the absolute polarization extinction ratios, $|ER_1|$ and $|ER_2|$ for TE and TM mode, were calculated respectively, which is in relation to geometric parameters of PBS. L_c and the tolerance δL of the coupling length were calculated as well when H varied. They are listed in Table I.

TABLE I. POLARIZATION EXTINCTION RATIO IN RELATION TO THE GEOMETRIC PARAMETERS OF PBS

H /μm	*Lc /μm*	$\|ER_2\|$ /dB	$\|ER_1\|$ /dB	δL/μm ($\|ER_i\| \geqslant 15dB$)
6	186	17.45	17.02	±0.8
6.5	189.5	17.58	16.90.	-0.7~+0.9
7	192.8	17.06	17.36	-0.9~+0.7

In our tolerance analysis, the criterion we used is again the requirement that the TE/TM polarization extinction ratios be higher than 15dB. Employing L_c=189.5*μm*, polarization extinction ratios were simulated as *H* or *G changes*. Fig.3 shows that the fabrication tolerances of *H* is about *±0.1μm for* $|ER_i| \geq 15dB$ *in the zone of H=6.5±0.1μm.*

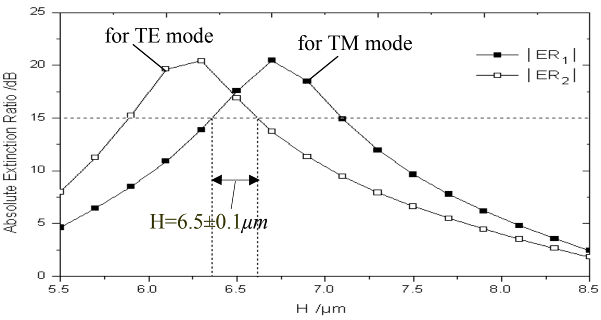


Fig. 3. The polarization extinction ratio $|ER_i|$ versus *H*

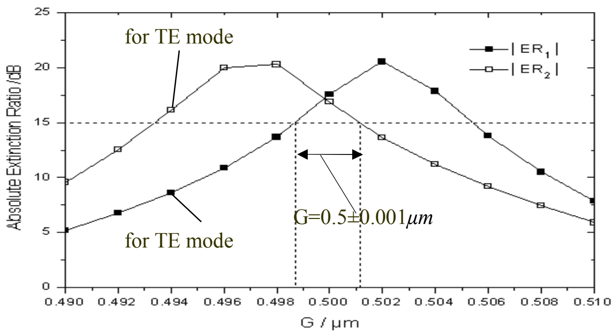


Fig. 4. The polarization extinction ratio $|ER_i|$ versus *G*

Fig.4 shows that the fabrication tolerances of G is about ±1nm for $|ERi| \geq 15dB$ in the zone of G=0.5±0.001μm.

The effect of wavelength on polarization splitting ratio was simulated as L_c=189.5*μm, H=6.5μm,* and *G=0.5μm*. Fig.5 shows that while $|\mathbf{ER_i}| \geq 15\mathbf{dB}$,the wavelength range in *1.549~1.551μm* with 3*nm* bandwidth. The polarization splitting ratio decreases from 0.55 to 0.41 as wavelength increases from 1.540 to 1.560, and reach *0.5* when the wavelength is *1.55μm.*

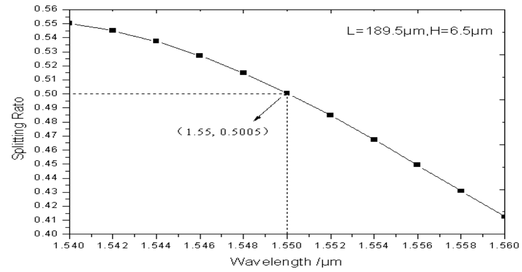


Fig. 5. The polarization splitting ratio versus wavelength.

III. CONCLUSION

In this work, we presented an optimized design of a PBS based on two close spaced parallel optical MNFs. We studied the characteristics of the device using 3-D FVBPM. We used numerical simulations to optimize the geometric parameters of the PBS, including the MNF diameter and their gap distance. The results show that high extinction ratio TE and TM splitting can be obtained at the wavelength of 1550 nm. We also studied the fabrication tolerance of the coupling length Lc, the MNF diameter D, and the gap distance G. This study has shown that an ultrasmall PBS can be made by taking advantage of the coupling characteristics of strong evanescent field between two micro/nano-fibers.

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