Asymmetric Excitation of Symmetric Single-Mode Y-Junction : The Radiation Mode Effects

Diaa A.M. KHALIL, Pierre BENECH & Smail TEDJINI
LEMO, 23 Avenue des Martyrs BP 257,
38016 GRENOBLE CEDEX- FRANCE
Phone (33) 76 87 69 76 Fax (33) 76 46 56 36

Abstract

This work studies, for the first time, a symmetric single-mode Y-junction under the asymmetric excitation by an optical fiber. The asymmetric excitation is due to fiber displacement with respect to junction axis. The power splitting between the two outputs of the junction is found to depend strongly on the fiber position. The theoretical analysis shows a splitting ratio as high as 14 dB, that could not be explained if the radiation mode coherent coupling is neglected. A GaAs/GaAlAs junction is tested and the experimental results confirm these theoretical predictions.

Introduction

The Y-junction is an important element frequently used in integrated optics. It is usually required to be a symmetric monomode junction and its analysis depends mainly on the behaviour of its fundamental mode. Recent works have shown that the coherent coupling of radiation modes, generated in the junction, may be very efficient for loss reduction either for the junction itself [1,2] or for a device based on it as the Mach-Zehnder interferometer[3]. However, in all these works the junction is assumed to be excited by its fundamental mode. This might be a good approximation if the input guide of the junction is long enough to filter all the higher order radiation modes. In practical systems this is rarely satisfied as the size reduction is also an important requirement. In this work we study the effects of the coherent coupling of the radiation modes generated at the input of a symmetric monomode Y-junction due to a non symmetric excitation. A classical analysis that considers only the guided mode propagation gives always a symmetric power division. However, when the coherent coupling of the odd radiation modes is considered, one output may be favoured with respect to the other which results in a distinction between the two symmetric outputs depending only on the excitation conditions.

Theoretical Analysis

The schematic diagram of the studied junction is shown in Fig.1-a. The guiding structure is a GaAs/GaAlAs strip-loaded one whose cross-section is shown in Fig. 1-b.

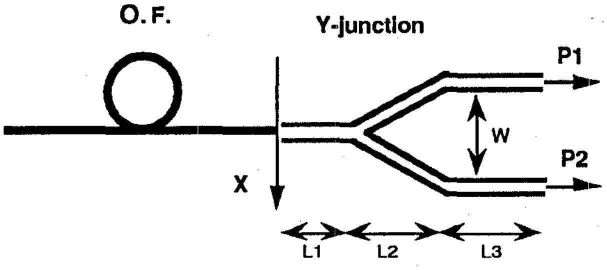


Fig.1-a) Schematic diagram of the studied Y-junction.

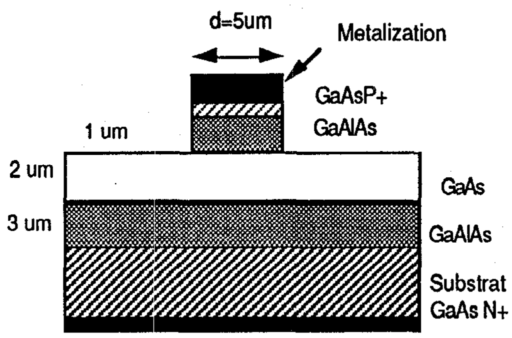
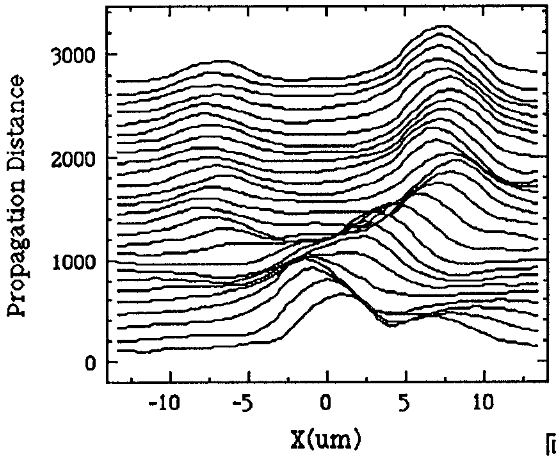


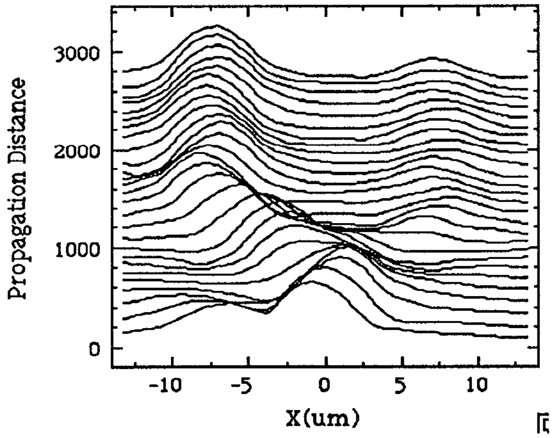
Fig.1-b) GaAs/GaAlAs strip-loaded guiding structure of the studied Y-junction.

Using the Effective Index Method, the two dimensional waveguide is replaced by an equivalent step index slab waveguide which is then studied using the Beam Propagation Method[3] BPM. The optical guides of the junction are designed to be single mode at $\lambda=1.3\mu m$ and the junction geometry is chosen such that its losses become negligible when it is excited by its fundamental mode. In our analysis, we assume that the junction is excited by an input field of a Gaussian distribution which is a good approximation for the field of a single mode fiber. The asymmetry of the excitation is due to the displacement "X_f" of the fiber axis with respect to the junction axis of symmetry. For $X_f = 0.0$ the fiber is perfectly aligned with the input guide of the junction and then only the even modes are excited which gives a splitting ratio between the two arms, $\eta = [P_1/P_2] = 1$ (0 dB). For $X_f \neq 0$, a fraction of the input power is coupled to the odd radiation modes of the input guide. The interference of this group of odd modes with the guided mode results in the oscillations of the field maximum around the centre of the input guide. Thus, depending on the direction of the fiber displacement, and the geometry of the junction, the power coupling to one branch of the Y-junction may be favoured with respect to the other.

The optical field distributions in the Y-junction, calculated by the BPM are shown in Fig.2 a,b for two positions of the injection fiber $X_f = \pm 3$ µm. The field oscillations could be observed in both the input and the output guides. Increasing the fiber displacement X_f increases the amount of power coupled to the odd radiation modes and hence the splitting ratio η is expected to increase. However, the increase of X_f decreases also the amount of power coupled to the guided mode of the structure. This could be seen in Fig.3 which gives the amount of power coupled to both the guided and radiation modes of the input guide as a function of the fiber position. This is calculated by projecting the input field on the guided mode of the structure as well as the radiation modes. The projection on the radiation modes is achieved by sampling their continuous spectrum as previously explained in ref. [2]



a-) $X_f = -3$ µm



b-) $X_f = 3$ µm

Fig.2 Electric field distribution in the Y-junction with : L1=440 µm , L2=900 µm and W=10 µm under two different excitation conditions.

One notices that, for a perfect alignment of the fiber, about 90% of the input power is coupled to the guided mode and no power is coupled to the odd radiation modes. Increasing X_f, the power coupled to the radiation modes increases rapidly and for $X_f = 5\mu m$ the power in the guided mode is approximately equal to that coupled to the odd radiation modes. This means that after this value of X_f, the increase of X_f reduces the oscillation amplitude and, consequently, the splitting ratio. In the limiting case, when X_f becomes much greater than the guide width "d", all the power is effectively coupled to the radiation modes and the optical field propagates in the equivalent substrate governed by the classical diffraction.

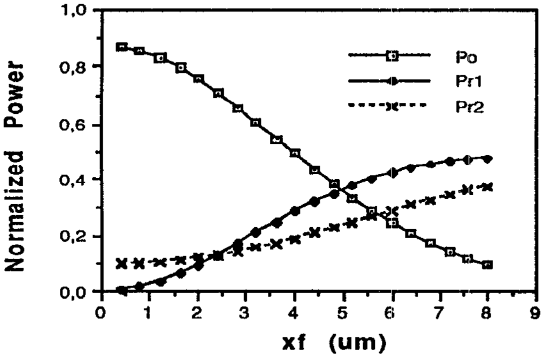


Fig.3 Normalized Coupled Power for guided mode (Po), odd radiation modes (Prl), and even radiation modes (Pr2).

These predictions are confirmed theoretically by calculating the splitting ratio η as a function of the fiber displacement X_f. Fig.4. shows the calculated splitting ratio η (X_f) between the two outputs of the Y-junction for two input waveguide lengths L_1= 500 μm and 440 μm.

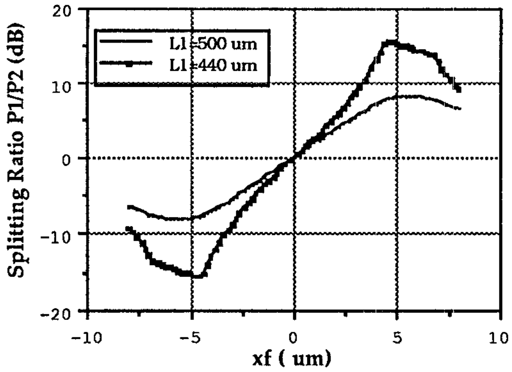


Fig. 4 - Theoretical splitting ratio as a function of the fiber displacement for L_1=440 et 500 μm.

The change of the length L_1 has mainly two effects: i) the coherence of the group of radiation modes decreases with the increase of the propagation length and hence their effect becomes less important, ii) increasing L_1 changes the position of the branching section with respect to the periodic oscillation of the field maximum in the input guide and then changes the power splitting. Actually the splitting ratio is an oscillatory function of L_1 with a damping effect that results from the reduction of the radiation mode coherence during their propagation. A part of this damped oscillation is illustrated in Fig. 5.

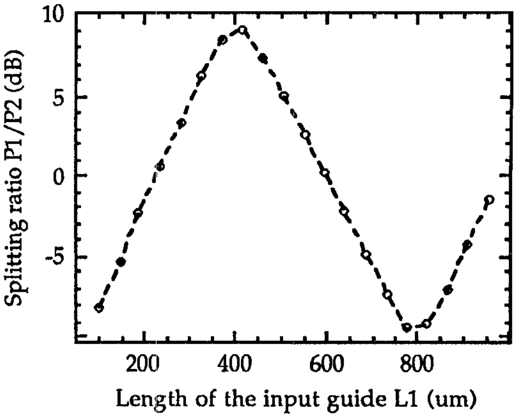


Fig. 5. Oscillatory behaviour of the splitting ratio as a function of L_1 (Fiber diameter = 9 μm).

Experimental Results

To verify these theoretical predictions the junction shown in Fig.1 with L_1=440 μm, L_2 = 900 μm, L_3 = 2700 μm and W = 10 μm is realised and tested at the wavelength λ=1.3 μm. The junction is excited using a single mode optical fiber whose mode diameter D_f is 9 μm. The fiber position is controlled in the 3 dimensional space using piezo-electric cells. A microscope objective is used to focus the output of the Y-junction on the screen of an infra-red camera connected to a monitor and a P.C. for data acquisition. The set up used for the measurement is given in Fig.6.

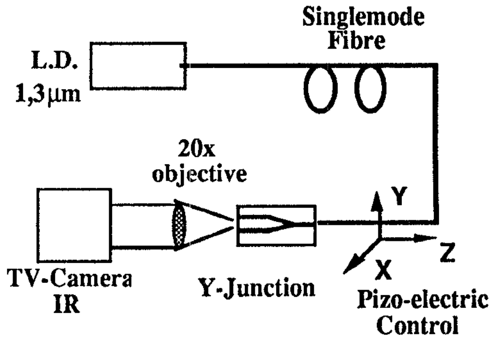


Fig. 6. Schematic diagram of the used experimental set up.

Fig.-7 shows the output optical intensity measured at X_f = ±1 μm. From such a measurement the splitting ratio "η" is deduced directly as the ratio between the two maxima of the output intensity.The relative displacement of the fiber is determined from the piezo-electric cell calibration and the reference position (Xf=0) is taken as the position at which the output of the junction is perfectly symmetric. The obtained results, shown in Fig.7, confirm well the theoretical predictions previously stated. A splitting ratio as high as 12 dB is obtained for about 2,5 µm displacement. A good linearity is obtained for a range of about 4 to 5 µm. These results propose the Y-junction as a good candidate for specific non-traditional applications like its use as a displacement sensor with a good linearity and a very high sensitivity.

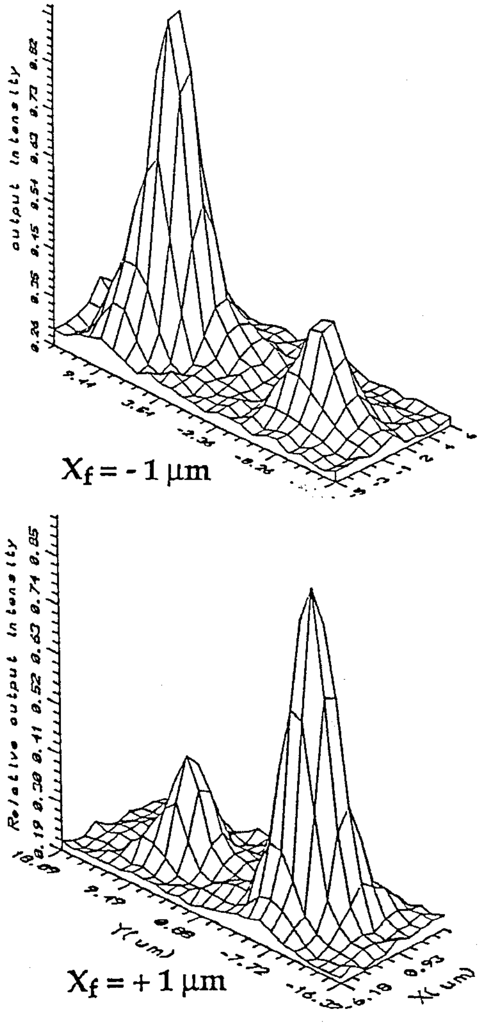


Fig.7. Measured output intensity for Xf = ±1 µm

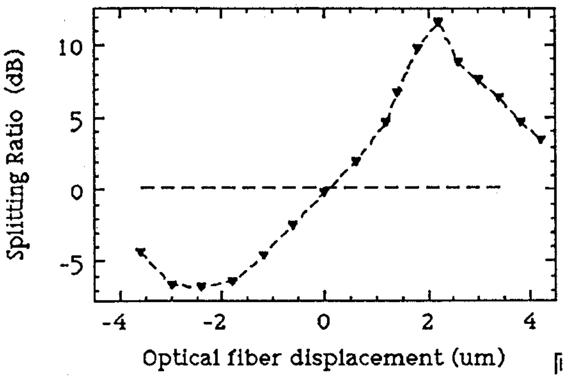


Fig. 8- Measured splitting ratio with Xf

Conclusion

This study shows that the coherent coupling of the input radiation modes affects greatly the performances of a symmetric single-mode Y-junction. Such effect may be of great importance for its practical applications like the Mach-Zehnder electrooptic intensity modulator in which the splitting ratio reduces greatly the modulation depth. On the other hand, it opens the door for another non-classical applications of the Y-junction. An example of these applications is to use it as a displacement sensor with a high sensitivity. Such a sensor will have the advantage to be insensible to the laser source stability as it depends on a differential power measurement.

References

[1] S. Chu and Pao-Lo Liu, "Low-loss coherent-coupling Y-branches", Opt. Lett., Vol. 16, No.5, pp 309-311, March, 1991.

[2] Diaa Khalil and S.Tedjini, "Radiation modes in integrated optic discontinuities" Eleventh European symposium on optoelectronics, Opto91, Paris, 26-28 March 1991.

[3] Diaa Khalil and S.Tedjini, "Coherent coupling of radiation modes in Mach-Zehnder electrooptic modulators", to be published, IEEE J. Quantum Electronic. May 1992.

[4] M.D. Feit, J.A. Fleck, "Light propagation in graded index optical fibers", Applied Optics, Vol. 17, n°24, pp. 3990-3998, Dec. 1978.