1P1-3

Analysis of Contribution of Dielectric Change in Optical Orbital Angular Momentum Mode Conversion by Elastic Vortex Wave

弾性波渦による光軌道角運動量モード変換における誘電率変化の寄与の解析

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1. Introduction

In the future optical network, optical orbital angular momentum (OAM) mode multiplexing will be a potential technique for large capacity transmission because optical OAM modes can theoretically take infinite modes with different mode order number. For optical OAM mode multiplexing, it is required to flexibility generate and handle plural optical OAM modes. Therefore, efficient methods to generate optical OAM mode is important. In this study, we discuss optical OAM mode conversion by acousto-optic interaction using elastic vortex waves.

2. Optical OAM mode

We consider Laguerre-Gaussian modes as optical OAM mode. The Laguerre-Gaussian modes are represented as $\mathrm{LG}_{\nu n}$ with ν as the number of rotation order, n as the number of node order in fiber radial direction. Electric field of the LG mode is expressed by

$$\mathrm{LG}_{\nu n}(r,\theta,z) = E(r)\mathrm{e}^{i\nu\theta}\mathrm{e}^{-i\beta z} \quad (1)$$

The intensity and phase profile of LG_{10} is shown in Fig.1 and Fig.2.

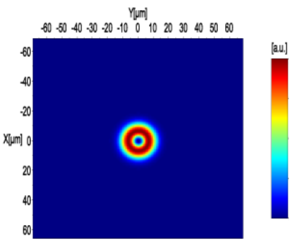

Fig. 1 Intensity profile of LG_{10}

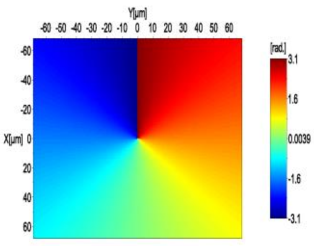

Fig.2 Phase profile of LG_{10}

3. Elastic vortex wave

Elastic vortex wave (EVW) is an ultrasonic wave having OAM. The EVW can be synthesized by two orthogonally propagating flexural waves having $\pi/2$ phase difference. The displacement components of EVW can be written as

$$u_r(r,\theta,z) = U(r)\mathrm{e}^{jm\theta}\mathrm{e}^{-jkz} \quad (2)$$
$$u_\theta(r,\theta,z) = V(r)\mathrm{e}^{jm\theta}\mathrm{e}^{-jkz} \quad (3)$$
$$u_z(r,\theta,z) = W(r)\mathrm{e}^{jm\theta}\mathrm{e}^{-jkz}. \quad (4)$$

$\mathrm{e}^{jm\theta}$ indicates that EVW has OAM and spiral phase front. We show the absolute value and phase profile of u_z component for m=1 in Fig.3 and Fig.4. Like u_z, u_r and u_θ have the same spiral phase profile and therefore have OAM [1][2].

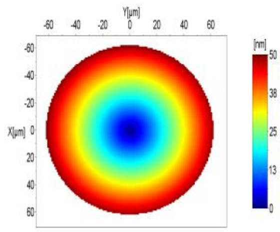

Fig. 3 Absolute value of u_z

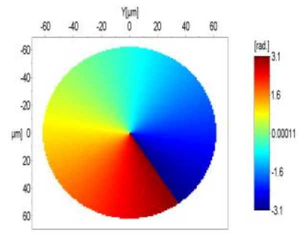

Fig.4 Phase profile of u_z

4. OAM mode conversion by elastic vortex wave

According to previous reports, elastic wave can convert optical mode by acousto-optic interaction. Moreover, EVW that is ultrasonic wave having OAM can convert optical OAM mode[3][4]. Generally, optical mode conversion using optical mode coupling can be analyzed by calculating mode coupling equations [5][6]. The mode coupling equations can be written as

$$\frac{dA_p(z)}{dz} = \sum_{l=0}^{n} A_l(z)\vartheta_{pl}e^{i(\beta_p-\beta_l-k_0)z}, \quad (5)$$

where, ϑ_{pl} is the mode coupling coefficient and is given by

$$\vartheta_{pl} = \frac{\omega}{4(\beta_l-\beta_p)}\iint \frac{E_p(r,\theta)\cdot E_l^*(r,\theta)}{N_p N_l}\frac{d\varepsilon}{dz} r dr d\theta. \quad (6)$$

We can calculate mode conversion efficiency from these equations. Here, $\frac{d\varepsilon}{dz}$ is an important term induced by EVW. Displacements of EVW induces periodic dielectric change in optical fiber. These dielectric changes contribute to acousto-optic interaction. These dielectric changes can be derived by eqs.(2)-(4) and are written by 6 components in simplified matrix notation.

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$$\Delta\varepsilon = [\Delta\varepsilon_1 \quad \Delta\varepsilon_2 \quad \Delta\varepsilon_3 \quad \Delta\varepsilon_4 \quad \Delta\varepsilon_5 \quad \Delta\varepsilon_6] \quad (7)$$

$$\varepsilon = \varepsilon_r + \Delta\varepsilon, \quad (8)$$

where, ε_r is the dielectric constant of the fiber. These 6 components of dielectric changes contribute to OAM mode conversion.

5. Numerical calculation result

We show a setup for the numerical calculation in Fig.5. We consider optical OAM mode conversion between LG_{00} and LG_{10}. In considering this mode conversion, we need to use EVW with frequency of 0.3918MHz that satisfies the phase-matching condition. Here, we set the parameter to optical wavelength 1550nm, max displacement of EVW 50nm. We show the calculated results in Figs. 6 and 7. From Fig.6, it can be seen that a perfect mode coupling is achieved with a propagation length of about 35 mm in the mode conversion between LG_{00} and LG_{10}. Moreover, from Fig.7, we can find the contribution of each component of dielectric changes induced by EVW. The components of $\Delta\varepsilon_1$ to $\Delta\varepsilon_5$ contribute to mode conversion. However, contribution of $\Delta\varepsilon_6$ is very small.

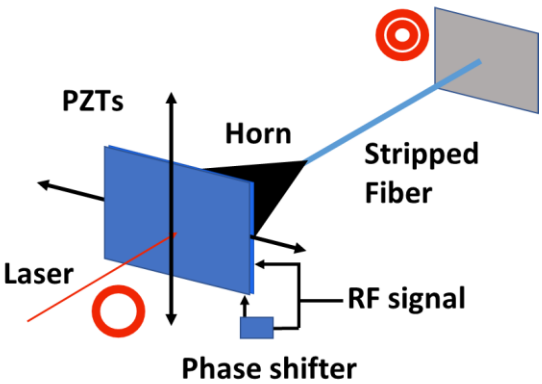


Fig.5 Simulation setup for optical OAM mode conversion.

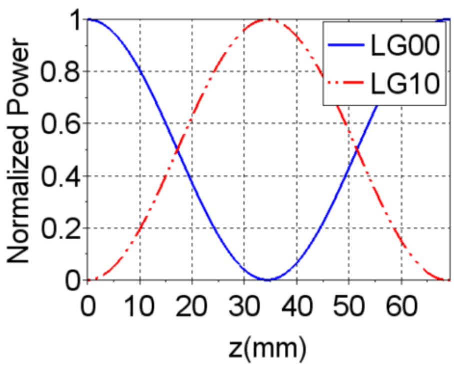
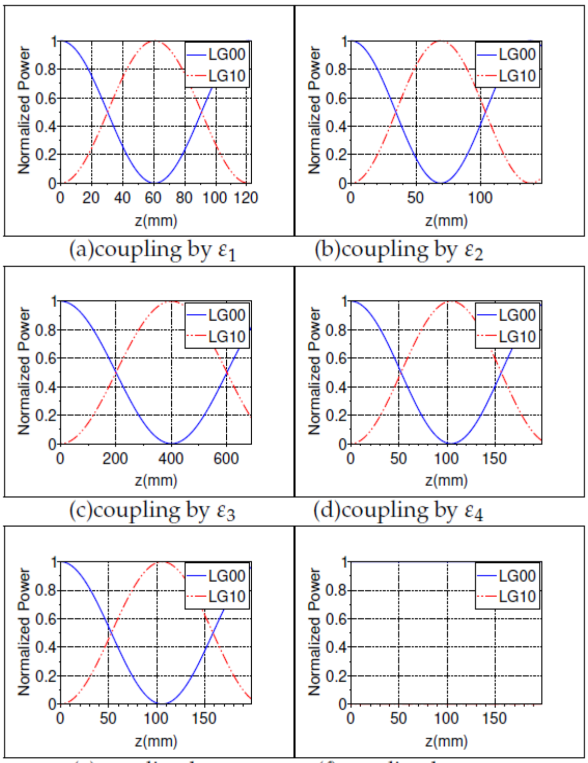


Fig.6 OAM mode conversion between LG_{00} and LG_{10} along the propagation length.



(a)coupling by ε_1 (b)coupling by ε_2
(c)coupling by ε_3 (d)coupling by ε_4
(e)coupling by ε_5 (f)coupling by ε_6

Fig.7 Contribution to mode conversion of Dielectric change components by EVW.

6. Conclusion

In this study, we clarified mode conversion efficiency and its contribution from each component of dielectric changes in optical OAM mode conversion in the squared graded index optical fiber.

References

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