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Coherent Tunnelling Adiabatic Passage in Fiber Geometry

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Abstract: This paper presents a mimic scheme of stimulated Raman adiabatic passage (STIRAP) in an optical fiber. An analogy is shown between the three level atomic system and the three modes of the optical fiber. It is possible to achieve an interaction using a pair of superimposed long period gratings where the fundamental core mode couples to another core mode via an intermediate cladding mode. The intermediate cladding mode gets negligibly excited and is known to work as dark mode.

Introduction:

Stimulated Raman adiabatic passage (STIRAP) technique in a three level system is the transfer of light between two levels assisted by an intermediate level with negligible excitation, thus defining the adiabatic behavior in the transfer of light. This technique has been realized in photonic integrated circuits by allowing light to couple from one waveguide to other via a central waveguide[1] wherein adiabatic transfer is ensured by maneuvering the separation between these waveguides[2]. Being the spatial analogue of STIRAP technique, the coherent tunnelling adiabatic passage (CTAP) in waveguides opens new avenues for device designing to achieve various functionalities in photonics such as mode transformers, beam splitters, polarization rotators[3-5], etc.. Adiabatic coupling in multimode waveguides has been achieved using CGPH[6] (computer generated planar holograms). We show coherent tunneling adiabatic passage in a standard SMF-28 fiber that utilizes a scheme of superimposed long period gratings (SLPGs) and involves two core modes and one cladding mode.

Analysis:

The fiber is made of fuzed silica (SiO_2) with 3.1 % GeO_2 doping in the core region. The core and cladding radii are 4.1 µm and 50 µm (etched cladding), respectively. Simulations are carried out at the wavelength of 633 nm where the geometry allows two azimuthally symmetric core modes ($LP_{0,1}$, $LP_{0,2}$) followed by cladding modes. Figure 1 shows the schematic of the fiber geometry with SLPGs. Grating I couples from fundamental core mode ($LP_{0,1}$) to the higher order cladding mode ($LP_{0,17}$) grating II couples from this selected higher order cladding mode to the $LP_{0,2}$ core mode with corresponding grating periods Λ_1 and Λ_2, respectively. L_g is the grating length which is the distance over which the three mode interaction takes place. Analysis for the three mode coupling has been carried out using standard coupled mode theory[7]. The perturbation in the refractive index profile of the fiber core that accounts for the SLPG pair is given by:

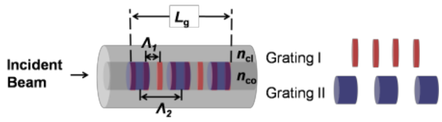

Fig. 1: Schematic of the fiber geometry showing SLPG

$$\delta n'(z) = \Delta\bar{n}'(z) + \Delta n_1(z)\sin\left(\frac{2\pi}{\Lambda_1}z\right) + \Delta n_2(z)\sin\left(\frac{2\pi}{\Lambda_2}z\right) \tag{1}$$

with $\Delta\bar{n}'(z)$ being the average z - dependent index that can be written as $\Delta n_1(z)+\Delta n_2(z)$. Δn_1 and Δn_2 are the z - dependent peak refractive indices of grating I and grating II, respectively. The values of the cross coupling coefficients of both the gratings depend directly on these peak refractive indices, thus become z - dependent. The three mode coupled equations can be represented in the following matrix form that can be solved by simplifying into an eigen value equation:

$$\zeta'(z) = \bar{T}\zeta(z) \tag{2}$$

with:

$$\zeta(z) = \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix}; \zeta'(z) = \frac{d}{dz}\begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix}; \bar{T} = \begin{bmatrix} 0 & \kappa(z) & 0 \\ -\kappa(z) & 0 & \kappa'(z) \\ 0 & -\kappa'(z) & 0 \end{bmatrix} \tag{3}$$

where $\kappa(z)$ and $\kappa'(z)$ are the cross coupling coefficients for grating I and II, respectively.

Results and Conclusion:

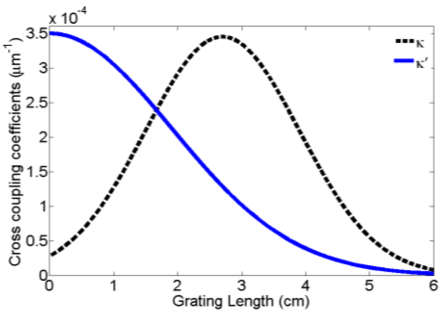

Fig. 2: Variation of cross coupling coefficients with respect to the grating length.

Figure 2 shows the variation of cross coupling coefficients for the two gratings along the grating length. It is clear from the figure that the variation follows a Gaussian profile such that the cross coupling coefficients reach the same peak value but at different positions in the grating. This comes as the direct consequence of the peak refractive index profile variation which is independent for both the gratings. As the fundamental mode is excited, coupling is stronger between the two unexcited modes than the mode which carries all light. The initial coupling between the fundamental core mode and cladding mode is weak. Thus, the scheme is counter-intuitive. Figure 3 shows the variation of fractional power in the three participating modes with respect to the grating length. It can be observed that due to the weak coupling between fundamental core mode and the cladding mode, and strong coupling between the cladding mode and $LP_{0,2}$ core mode, power launched in the $LP_{0,1}$ core mode gets immediately coupled to $LP_{0,2}$ core mode. Thus, despite the fact the power cannot be transferred without the participation of the intermediate $LP_{0,17}$ cladding mode, it gets negligibly excited. Light tunnels to the $LP_{0,2}$ mode and the intermediate cladding mode works as a dark mode. This is similar to the dark state in three level atomic system.

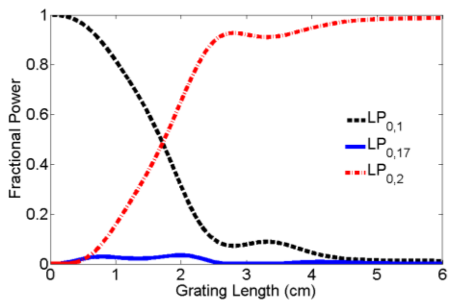

Fig. 3: Variation of power in the three modes with SLPG length.

In conclusion, an adiabatic route to power transfer between two modes via an intermediate mode that participates without getting appreciably excited is shown in optical fibers. It is realized that the dark mode exist in the fiber geometry. The result may be of interest in the optical networking and communication.

References

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