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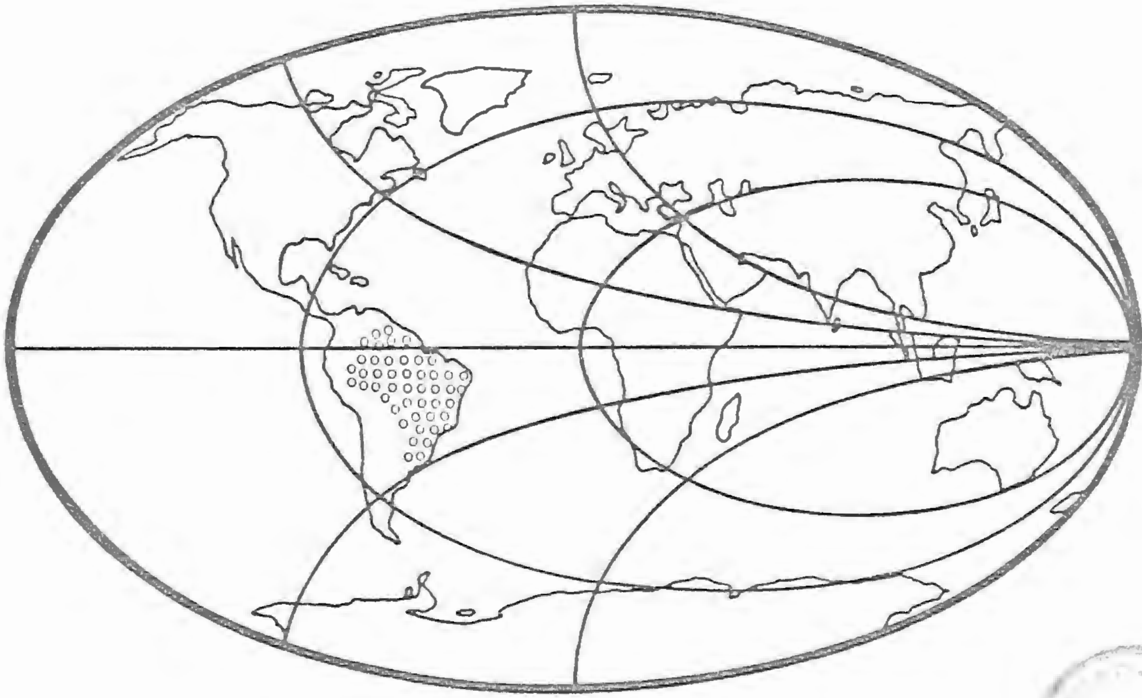

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DEVELOPING AN ALL FIBER OPTICS TUNABLE BEAM SPLITTER

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ABSTRACT: We present a simple mechanism to induce optical d. c. switching at sub-dB losses on a single-mode fused coupler. The optical splittage is controled by elastically stressing the coupler. A 7 gf load applied axially to the coupler produced 55% of change in the coupling ratio. These results are interpreted assuming elastic deformations of the fabricated structure, which behaves as an optical beating element.

INTRODUCTION: The rapidly developing applications of single-mode fibers in communications have begun to produce tangible demands for couplers and related devices such as tunable beam splitters and multiplexers. These devices may be built from discrete optical components such as microlenses, prisms, beam splitters among many others. Unfortunately, devices made from discrete components in general present low mechanical stability and therefore are not reliable. Any technique of manufacturing reliable devices should avoid discrete components, to rely only on fibers and their required packaging structures. This paper presents a single mechanism on which an all fiber tunable beam splitter can operate at sub-dB losses. The optical switching is induced by elastically stressing a fused monomode coupler which acts as an interferometric structure. Applying a 7gf load axially to the coupler, we observed variation of 55% in the coupling ratio. These results are interpreted assuming elastic deformations of the structure built. The total insertion loss measured was 0.10 ± 0.05 dB, which turns to be insensitive to the mechanical load required for operation.

MODELING: The device described herein was fabricated in a manner similar to the fused single-mode couplers which have been reported elsewhere /1,2/. In review, fused couplers are constructed by bringing together and fusing and tapering a central section of a fiber pair. As the coupler is being fabricated, the output intensities are monitored. The process is interrupted when the desired coupling ratio is obtained. This value is typically 50%. However, if the tapering process is continued, the coupled power will undergo sinosoidal oscillations or "beats" as shown in Fig. 1. The coupler is said to have been pulled through one beat length l when the coupled power has cycled through one complete sinosoidal oscillation.

The coupling mechanism is assumed to take place in a composite waveguide in which the fused glass structure at the taper waist is the core (refractive index $N_c \approx N_1$), and the cladding is the external medium (refractive index Next) surrounding the coupler. In this manner, the coupling is

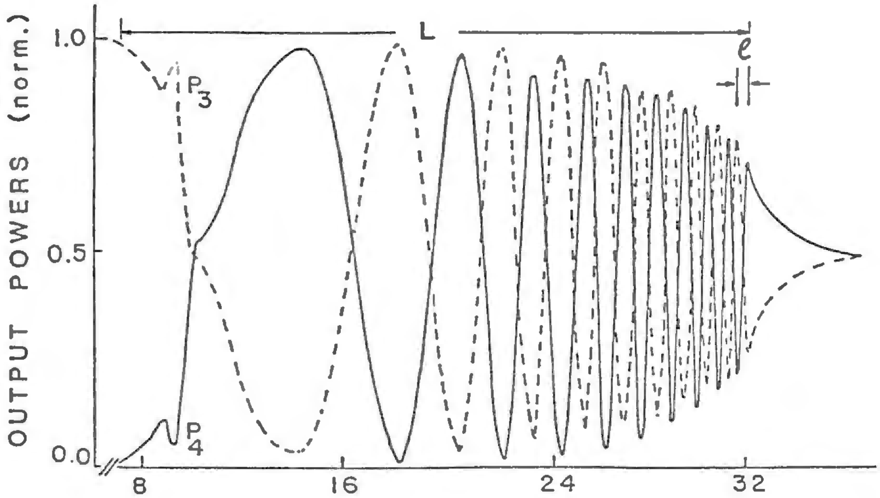

FIG. 1 - Behavior of the output powers P3 and P4 during the tapering process. Final dimensions are L = 26 mm and l = 0.45 mm as defined in text. The total insertion loss is approximately 0.1 dB.

described by the mode beating model of Bures et al /3,4/ in which energy transfer in the composite waveguide is betweeen the two lowest symmetric and antisymmetric modes bound by the glass external-media interface. It is assumed that, as light propagates down stream through the transition taper to the composite waveguide structure at the coupler waist, the modal electromagnetic fields gradually change from being bound by the waveguide with a glass doped core (refractive index N2), and glass cladding (N1) to one with a larger glass core and an external medium as the cladding. The reverse process occurs in the taper leading away from the couler waist.

Due to the birefringent cross section of the composite waveguide, the propagation constants of the x- and y-polarizations are slightly different. This gives rise, in long tapers, to a slow amplitude modulation of the rapid sinosoidal output powers as shown in Fig. 1. If the fused region is long enough, it is possible to occur complete dephasing betwenn the two polarizations. Potentially, there are many applications which can exploit these properties of long fused couplers. They include polarization beam splitters, spectral filters, modulators and switching, the latter being the theme of this paper.

For short tapers, i.e., tapers with interation lengths of the order of the coupling length ($L \gtrsim l$), the normalized crossport output power p_4 is simply given by

$$P_4 = \mathrm{Sin}^2\,(CL) \tag{1}$$

Where $C = C\,(\Delta n,\lambda,a) = \pi/2l$ is the coupling coefficient, a the smallest diameter at the waist, λ the wavelength, and Δn = Next - N1. On the other hand, if the taper is sufficiently long, i.e., $L \gg l$ it becomes necessary to take into account the influence of the slightly different coupling coefficients, and thus, the crossport output power is given by

$$P_4 = \tfrac{1}{2}\left(\sin^2 C_x L + \sin^2 C_y L\right) \qquad (2)$$

Where C_x and C_y are the coupling coefficients in the x- and y-directions respectively. Therefore, according to Eq. 2, the crossport output power can be modified by axially stressing the taper in such a way that $\Delta L/L = Y^{-1} S$, where Y is the Young Modulus for silica, and S the applied stress. The effect of an applied stress on the output powers is exemplified in Fig. 2b for $L \approx 1/2$.

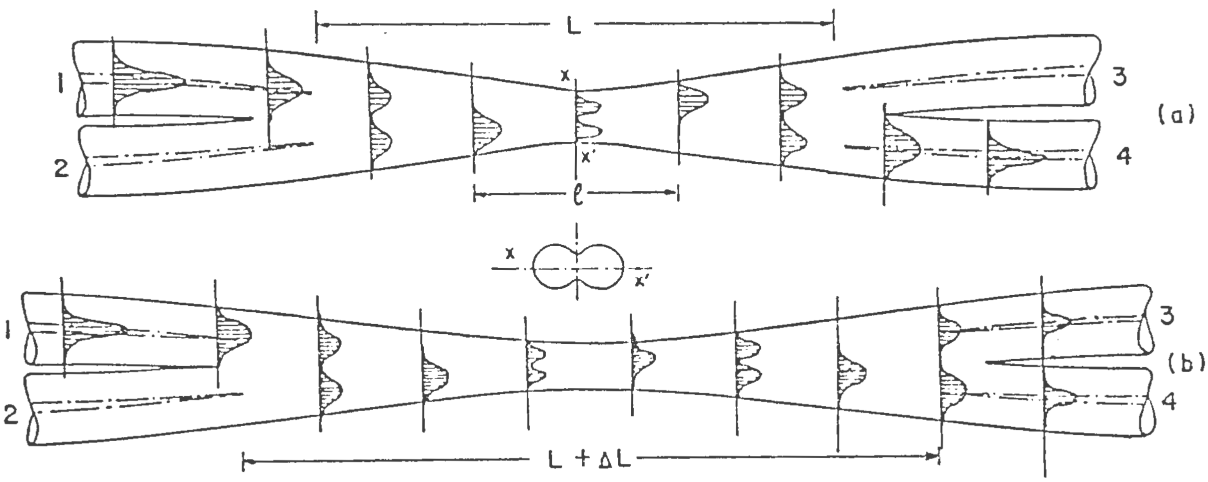

FIG. 2 - Pictorial view of the biconical structure. (a) Without load the interaction legth L, and the beating length ℓ are defined. (b) The structure is stressed in such a way that $\Delta L \approx \ell/2$.

RESULTS AND DISCUSSION: The variation of the coupling ratio $r = P4/(P3+P4)$ with the force F applied axially to the taper by two eletromechanical transducers is shown in Fig. 3 for three different wavelengths. Its sinosoidal dependence on F is explained by the beating model presented above, assuming elastic deformations of the taper structure. One observes in Fig. 3 that the variation in the coupling ratio r is limited to approximatelly 55%, and does not reach the full switch as would be desired. This occurs because the tapering process was interrupted before reaching the complete dephasing of C_x and C_y. Continuing the tapering process throughout this point, the output power would recover the full sinosoidal amplitude of oscillations as predicted by Eq. 2, and demonstrated experimentally by Bilodeau et al /5/. According to Eq. 2, the behavior of the coupling ratio during tapering is illustrated in Fig. 4.

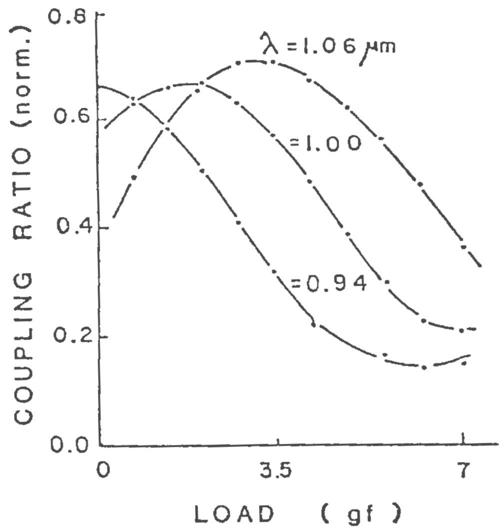

FIG. 3 - Dependence of the coupling ratio on axial stress for three different wavelenghts.

The dependence of the coupling ratio on the transmitted wavelength is shown in Fig. 5 for the unstressed structure, and to the taper submitted to 7 gf. This spectral response of crossport power for beam splitters constructed from fused-taper couplers was recently analysed by Snyder /6/. According to him, the coupling coefficients Cx and Cy are approximately given by

$$C_i(\lambda,a_i) = \frac{\pi}{L}\left[\frac{3}{8}\frac{Vo}{\Delta}\left(\frac{\lambda}{\lambda_o}\right) + \frac{ay}{a_i}\left(\frac{\lambda}{\lambda}\right)^2\right] \quad (3)$$

where $i = (x,y)$, $Vo \approx 50$, $\Delta \approx 0.3$, $\lambda o \approx 0.68$ microns, $a_x = 2a_y = 11$ microns for the final structure obtained after the tapering process shown in Fig. 1.

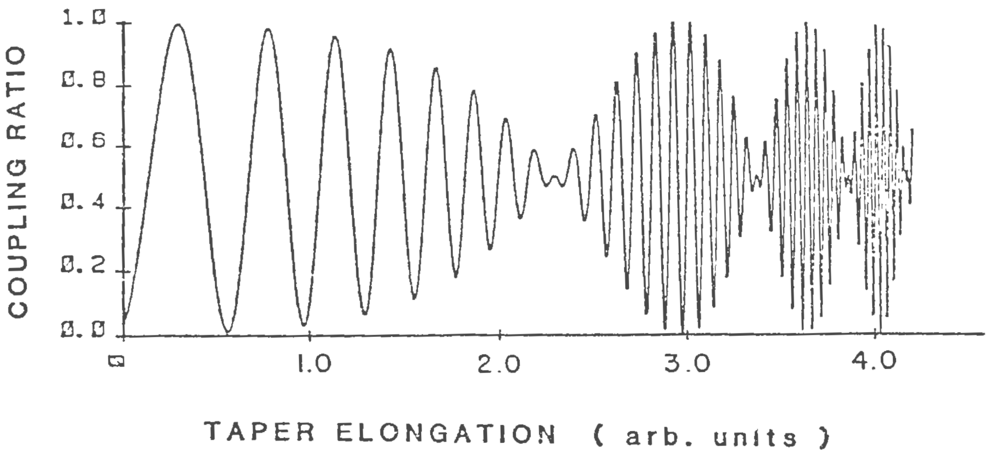

FIG. 4 - Theoretical behavior of the coupling ratio during tapering according to Eqs. 2 and 3.

The key to such analytic expression for C_j (λ) is that the composite waveguide is highly multimoded (V >>1), and the weak guided approximation still holds. Changing either the diameter of the waist a (during tapering) or the transmitted wavelength λ results in an oscillatory response characterized by two scales; a polarization-independent rapid oscillation (proportional to λ), and a polarization dependent slow variation proportional to λ^2 as shown in Fig. 5. Moreover, the first linear term on the right hand side of Eq. 3 is two orders of magnitude grater than the second one. Therefore, effects of polarization are only detectable in long tapers where the quadratic term becomes significant.

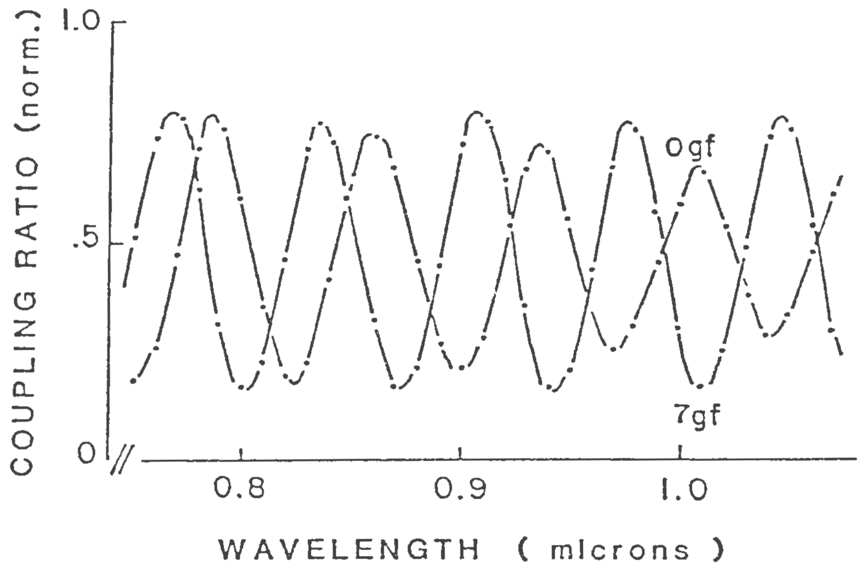

FIG. 5 - Dependence of the coupling ratio on the transmitted wavelength for the unloaded taper and for the taper submitted to 7 gf.

In order to quantify the hypothesis of elastic deformations inducing optical beating, we estimated the elongation necessary to cycle the coupled power through one complete sinosoidal oscillation, comparing it to that measured experimentally during the final tapering. According to Fig. 4, 7.0 ± 0.5 gf cycles the coupled power through one cycle, which from Hooks' Law gives $\Delta L/L = 0.013 \pm 0.004$ for Y (SiO_2) = (10 ± 1) x 10^{11} dynes/cm. One the other hand, one observes in Fig. 1 that the final taper structrure has a normalized coupling length $l/L = 0.016 \pm 0.003$ in agreement to the estimated elongation obtained from the elastic assumption.

In conclusion, we presented in this paper a simple mechanism to induce tunable optical d.c. switch, at low losses, on an all fiber fused coupler. The conceptual simplicity of this device makes it attractive for operation in single-mode fiber networks.

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