The amplitudes of the beams reflected from the front and back surfaces of the sample are not equal because the latter one of the beams is attenuated due to twofold transition through the front surface of the sample. Consequently, the ratio of their amplitudes in the location of the interference minimum is equal $1:R^2$. $R^2$ is the ratio between amplitudes of the reflected and incident beams, respectively. The intensity in the location of the interference minima is then $I_m = I_1 R^2$ and $I_R = I_2 R^2$ in the place of interference maxima, where $I_1 = I R$ and $I$ is the intensity distribution in the beam that is illuminating the sample with optical record.

2.4. Enhancement of the image contrast

For purposes of exact interpretation of obtained image of interference field, it is useful if the minima of the interference pattern are displayed as thin dark fringes. This is the reason why it is convenient to display the image of the interference field with the maximum contrast. Taking into account the extreme situation, we can use the binary notation – full light and darkness. It is convenient to choose the discriminatory level as close to minimum of interference field intensity as possible. However, in case of non-homogeneous beam is used to illuminate the sample, the intensity in the location of the minima depends on the position of that place. Now, if we set the discriminatory level according to minima located in region of maximal intensity of illuminating beam (in the center of the beam in case of the beam with Gaussian distribution of intensity) we can not display the interference fringes in the region where the illumination is weaker (at the periphery of the field) (see Fig. 7).

![Fig. 7. Two values of the discriminatory level for binary notation of the interference field.](image)

If the intensity of the interfering waves were the same, the intensity in the minimum of interference field would be zero. It means it wouldn’t depend on homogeneity of illuminating beam. Imaging a record using an interferometer enables to control the intensities of interfering waves by means of appropriate filters. One can doing this make the intensity be independent on the homogeneity of illuminating beam in the place of interference minimum. This is another advantage of imaging using interferometers when comparing with the imaging by means of intensity of waves reflected from surfaces of the sample.

3. CONCLUSION

Following the description of three ways of interference imaging presented in this contribution, one can deduce the choice of the optimal setup depends on the value of refractive index of the sample and the range of the refractive index variation, which is going to be displayed, respectively. Samples with refractive index equal 2 or greater have the reflectivity coefficient greater than 0.3. It means that beams with amplitude determined by $R$ (Michelson interferometer) significantly influence the interference image. The distortion may be as large as no imaging of in-homogeneities is possible. This is the reason why it is more convenient to use imaging by means of interference of waves reflected from the surfaces of the sample or imaging using Mach-Zehnder interferometer for samples with large refractive index. Though the imaging by interference of waves reflected from the surfaces is matchless the simplest one, the use of this technique (namely for imaging of one-dimensional in-homogeneities) needs the special sample. The form of the sample assures that interference fringes are perpendicular to orientation of in-homogeneities. In that case, it will be advantageous to use Mach-Zehnder interferometer for samples with large refractive index or Michelson interferometer for samples with small refractive index.

REFERENCES


1. INTRODUCTION

The potential of twin core fiber based components was recognized in the early report on this subject [1]. Recently, it is most used at spectral filters [2], for the equalisation of signal power in particular WDM channels or tunable directional coupler [3] because the parameters of twin core fibres depend on eventual mechanical fibre deformation quite sensitively, it is important to know how the deformation influences them. On the other hand their sensitivity could be used for sensors constructions. This is the reason why the presented paper is devoted to this topic.

2. ANALYSIS

The spectral properties of twin core fibres depend on the value of coupling coefficient $C$ and also on the difference of effective propagation phase constants $\Delta \beta$.

When only one of the cores is excited then the powers in the eventually cores are

\[ P_1(z) = 1 - F^2 \sin^2 \left( \frac{z}{L_e} \right), \]

\[ P_2(z) = F^2 \sin^2 \left( \frac{z}{L_e} \right), \]

where $P_1(z)$ is power in excited core and $P_2(z)$ is power in second core, $F$ is coupling efficiency and depends on difference of phase constants appertaining to particular cores $\beta_1 - \beta_2$.

\[ F = \sqrt{1 - \left( \frac{\beta_1 - \beta_2}{4C^2} \right)^2} \]

and coupling length $L_c$ is

\[ L_c = \frac{\pi}{2C^2 \left( \frac{\beta_1 - \beta_2}{4C^2} \right)^2} \]

The coupling coefficient $C$ is given by overlapping integral

\[ C = \int_0^{2\pi} \left| \int_0^{2\pi} \int \psi_e(r, \phi) \psi_o(r, \phi) \psi_e(r, \phi) \psi_o(r, \phi) \right| dr \phi \]

where $\psi_e(r, \phi)$ and $\psi_o(r, \phi)$ express the profile of investigated fibre toward surroundings (cladding) in cylindrical coordinate system, $\psi_e$ and $\psi_o$ are wave functions described transverse distribution of field of the cores in isolation.

The fibre deformation influences both of these parameters. The character of this influence strong depends not only on deformation geometry but on fibre geometry too. The signal dependence on deformation geometry is clearly seen from the bending of twin core fibre.
For example, let such bend of twin core fibre is performed that curvature centre lies on symmetrical (parallel) cores. The length change of all cores is identical so the difference of phase propagation constants pertaining to particular cores is identical, too. The change of transmission properties can be caused only by variation of coupling coefficient. This variation can be activated by pattern change of mode functions involved bending. For small deformations (the diameter of cores is significantly smaller than radius of curvature), the fibre can be considered straight from optical field computation aspect. This means that such change invoke irrelevant change of fibre field and coupling coefficient, too. However, for such bending that curvature centre is situated on plane that runs through fibre cores it causes different changes of lengths of cores [5]. In consequence of this the difference of effective phase propagation constants arise, because the phase difference of field (which is in the plane vertical to the fibre) arise. Strictly speaking, it causes the change of the difference of effective propagation constants, because their difference didn't have to be equal before deformation.

It is similar for twin core fibre deformation in torsion. In torsion deformation of (cylindrical) twin core fibre with symmetrically located cores the torsion invokes the same lengths change of both cores, accordingly it make not change of difference of propagation constants. Though for twin core fibre where one core is located in the centre of the fibre and second one is located out of centre in distance \( r \) [6], the torsion deformation influences the difference of propagation constants, because the torsion invokes the change of length only of eccentric located core of the fibre.

The relative phase change of eccentric located core is indirect proportion of relative change of fibre length, which can be express by relation

\[
\delta \phi = \varphi_0 = \frac{\varphi_l - (\varphi_0 + \omega)}{\varphi_l}.
\]

where \( \varphi_l \) is length of core in non-deformed fibre, \( \varphi \) is angle of sliving and \( \omega \) express eventual "twist" of eccentric located core around centre core in state which it is taken for the state before deformation from macroscopic point of view (1.1).

It follows from relation (6) an interesting asymmetry of influence of torsion on variation of core length. It is the difference of effective propagation constants depends on lengths of cores, zero deformation (\( \varphi_0 \)) generates asymmetry of torsion influence on transmission properties of fibre.

In the fibre for which angle \( \varphi_0 \) is zero, the torsion influence is independent on direction of torsion. However, if in the "non-deformed" state \( \varphi_0 \) \( \neq \) 0, the effective phase constant of eccentric located core decreases if angles \( \varphi \) and \( \omega \) have identical signs and increases when their orientation is opposite. Consequence of this matter is more interesting if phase constants of particular cores of fibre \( \beta, \beta' \) are unequal. In this case of If one of the phase constants increases or decreases it makes the difference change \( \Delta \beta \) and also the change of modulation amplitude of transmission signal which depends on difference of effective phase \( \Delta \beta \) which is given by equations (1.4).

3. EXPERIMENTAL SET-UP AND RESULTS

We observed spectral dependencies of transmitted signals of particular cores in experimental set-up [7], which schema is shown in Fig.2.

![Fig.2. Experimental setup used for observation of spectral dependencies](image)

Light source is realised using an halogen lamp, which radiation was chopped and filtered by monochromator. The signal going from the monochromator is coupled to the exciting fibre. The end face of this fibre together with end face of twin core fibre is located on 3D micro movement stage. It allows that only one of the cores of twin core fibre could be excited. The second end face of twin core fibre is located on the second 3D micro movement stage where using a detection fibre the signal is transported to the detector and recorded in PC.

At investigation of experimental twin core fibre we really observed asymmetric dependence of transmitted signal on torsion deformation direction (fig.3).

From dependencies shown in Fig.3, it can be seen how the amplitude is changing in consequence of torsion of fibre.

![Fig.3. Spectral dependencies of transmitted signal P2 in torsion deformation twin core fibre with length 28 cm for angle \( \phi \) from 0 to 375](image)

The values given on Fig.4 are relative values, which related to the local amplitude of dependencies between 1550 to 1600 nm. This allows eliminating the variation of signal caused by different fibre excitation at different angles of torsion (due to imperfection of equipment at rotation of the fibre, beginning slide movement of fibre centre occurred what required a new adjusting of the exciting fibre to the exact fibre core).

5. CONCLUSION

The obtained results indicate that eccentrically located core is twisted around the central core in "non-deformed" fibre. It shows that quite simple investigation of influence of torsion on transmission properties could inform about various geometric of the fibre.

On the other hand the presented results also illustrate that such fibre can be used as a basic spectral filter with parameter control by torsion deformation of the fibre.
For example, let such bend of twin core fibre is performed that curvature centre lies on symetral (parallel) cores. The length change of all cores is identical so the difference of phase propagation constants appertaining to particular cores is identical, too. The change of transmission properties can be caused only by variation of coupling coefficient. This variation can be activated by pattern change of mode functions involved bending. For small deformations

\[ \Delta p = l_0 (\phi - \phi_0) \]

where \( l_0 \) is length of core in non-deformed fibre, \( \phi \) is angle of slewing and \( \phi_0 \) express eventual "twist" of eccentric located core around centre core in state which it is taken for the state before deformation from macroscopic point of view (fig.1).

It follows from relation (6) an interesting asymmetry of influence of torsion on variation of core length. It is because the difference of effective propagation constants depends on lengths of cores, zero deformation \( \phi_0 \) generates asymmetry of torsion influence on transmission properties of fibre.

In the fibre for which angle \( \phi_0 \) is zero, the torsion influence is independent on direction of torsion. However, if in the "non-deformed" state \( \phi_0 \neq 0 \), the effective phase constant of eccentric located core decreases if angles \( \phi \) and \( \phi_0 \) have identical signs and increases when their orientation is opposite. Consequence of this manner is more interesting if phase constants of particular cores of fibre \( \beta_1 \) and \( \beta_2 \) are on unequal. In this case of If one of the phase constants increases or decreases it means the difference change \( \Delta \beta \) and also the change of modulation amplitude of transmission signal which depends on difference of effective phase \( \Delta \phi \) which is given by equations (1-4).

3. EXPERIMENTAL SET-UP AND RESULTS

We observed spectral dependencies of transmitted signals of particular cores in experimental set-up [7], which schema is shown in fig.2.

![Fig.2. Experimental setup used for observation of spectral dependencies.](image)

Light source is realised using an halogen lamp, which radiation was chopped and filtered by monochromator. The signal outgoing from the monochromator is coupled to the exciting fibre. The end face of this fibre together with end face of twin core fibre is located on 3D micro movement stage. It allows that only one of the cores of twin core fibre could be excited. The second end face of twin core fibre is located on the second 3D micro movement stage where using an detection fibre the signal is transported to the detector and recorded in PC.

At investigation of experimental twin core fibre we really observed asymmetric dependence of transmitted signal on torsion deformation direction (fig.3).

From dependencies shown in Fig.3, it can be seen how the amplitude is changing in consequence of torsion of fibre.

![Fig.3. Spectral dependencies of transmitted signal P2 in torsion deformation twin core fibre with length 28 cm for angle φ form 0 to 375°.](image)

Also from the next figure it can be seen how the amplitude of transmitting signal depends on angle of twist for wavelengths 1550nm and 1680nm.

![Fig.4. The angle dependencies of transmitted signal P2 at two wavelengths.](image)

The values given on fig.4 are relative values, which relate to the local amplitude of dependencies between 1550 to 1600 nm. This allows eliminating the variation of signal caused by different fibre excitation at different angles of torsion (due to imperfections of equipment at rotation of the fibre, beginning slide movement of fibre centre occurred what required a new adjusting of the exciting fibre to the exact fibre core).

5. CONCLUSION

The obtained results indicate that eccentrically located core is twisted around the central core in "non-deformed" fibre.

It shows that quite simple investigation of influence of torsion on transmission properties could inform about various geometric of the fibre.

On the other hand the presented results also illustrate that such fibre can be used as a special spectral filter with parameter control by torsion deformation of the fibre.
Acknowledgement

We would like to thank Dr. Pavel Peteka from IREE Czech Academy of Science, Prague for providing the sample of asymmetric twin core fibre.

REFERENCES


APPLICATION OF OPEN CIRCUIT VOLTAGE DECAY TO THE CHARACTERIZATION OF p/n’ AND n/p’ EPITAXIAL LAYER

M. Ţapajna*, J. Pjenčák, A. Vrbický, P. Kúdelka, L. Harmaná

Department of Microelectronics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Štefánikova 3, 812 19 Bratislava, Slovak Republic

Summary High quality silicon epitaxial layers are inevitable in bipolar and/or unipolar technology. However, its properties are not as easy characterized as those of bulk material. The recombination lifetime is dominated by surface/interface recombination for thin layers, which epitaxial ones generally are. We have designed double structure with n’/p” and p’/n” epitaxial layer for open circuit voltage decay (OCVD) technique. In such a structure, injected carriers are constrained within lightly doped base by potential barriers of junction and high-low contact and their concentration can then decrease only by recombination. Carrier lifetime obtained by this manner yields information mainly about the defect properties of epitaxial layer. Performing OCVD measurement for high-level injection condition, also τ0 and τ1 could be evaluated.

1. INTRODUCTION

The open-circuit voltage decay (OCVD) technique was one of the earliest method for carrier lifetime determination [1]. It is easy to implement and interpretation of experimental data is fairly straightforward, moreover it is expected very good correlation to real electrical parameters of devices. In this method, a diode is forward biased and a steady-state excess carrier is established in lightly doped region. Once, the diode bias circuit is opened and subsequent excess carrier recombination is detected by monitoring open circuit voltage. High injection and low-injection lifetimes are then evaluated from two distinct regions of voltage transient respectively.

In bipolar and unipolar technology, epitaxial (epi) layers are routinely used because they contain fewer metallic contaminants and lower oxygen densities than bulk Cz wafers. The quality of these layers can be evaluated with recombination or generation lifetime measurement in some way [2, 3]. However, there may arise some uncertainty in lifetime measurement due to fact, that epi layers are generally thinner than minority carrier diffusion length, forasmuch as OCVD method (because the most commonly used techniques) measure the recombination lifetime. Parameter obtained in this manner yield more information about the surface and epitaxial layer/substrate interface than about the epi layer itself. Nevertheless, this difficulty can be overcome by growing of an epi layer with counter doping type than the substrate, i.e. making of n”/p or p’/n” junction respectively and subsequent creation of high-low contact with diffusion or epitaxial growth with higher doping concentration (Fig. 1).

This structure affect as the effective potential barrier for constraining of injected carriers within the lightly doped region, which can decrease with time only through electron-hole recombination.

When the high-low contact is grown in one technological step with epi layer e.g. by extending the impurity flow or using diffusion process, it is expected high-quality n”/p or p”/n interface respectively, with negligible low recombination velocity, hence, recombination lifetime is mostly influenced by bulk of lightly doped epi layer. Moreover, as will be mentioned in section 2, the width of lightly doped region should be less than an ambipolar diffusion length, thereby this structure is suitable for thin epi layer characterization.

In this paper, we have analyzed n”/p and p”/n” structures respectively, using both n and p’/n” growth for high-low contact preparation. Lifetime obtained from OCVD response using such a structures has been discussed according to experimental as well as simulated I-V characteristics.

2. THEORETICAL BACKGROUND

In this section, we consider structure as those in figure 2a) with short base width. The recombination lifetime is determined by three main recombination mechanisms: Shockley-Read-Hall (SRH) or multiplon recombination characterized by the lifetime τSRH, radiative recombination characterized by τ0, and Auger recombination τAuger according to relationship (4)