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Improvement of Overlap for 2×2 MZI Electro-Optic Switch Based on Lithium Tantalite ($LiTaO_3$)

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Abstract

This research introduces a method of an electro-optic effect and electro-refractive effect that considers very imperative for high-speed optical communication systems. In this research, it presents way by a reduction the gap between the electrodes d, and this technique achieves to solve the problem of overlap for Mach-Zehnder interferometer MZI electro-optical switch base on lithium tantalite $LiTaO_3$, also this technique suggests a model for analysis the effect parameters on the electro-optic overlap of the electro-optic switch as the ordinary positive changing of refractive index and a length of arm switch. This study achieves a better overlap by large positive changing refractive index with a suitable small length of arm about 8μm and low driving power at least 4V/μm. Also, for lithium tantalite $LiTaO_3$, this research achieves a better performance for system using the near infrared wavelength.

Keywords: Mach-Zehnder Interferometer (MZI), Electro-Optic Switch, Electro-Optic Effect, Electro- Refractive Effect, Lithium Tantalite $LiTaO_3$.

تحسين التشابك للمفتاح (2*2MZI) الكهروبصري المستندعلى الليثيوم تنتليات $LiTaO_3$

صادق عدنان حبيب

الخلاصة:

البحث يقدم طريقة التأثير الكهروضوئي وطريقة الانكسار الألكتروني التي تعتبر مهمة جدا" في انظمة الاتصالات الضوئية العالية السرعة . في هذا البحث يقدم طريقة لحل مشكلة التشابك للمفتاح الكهروبصري نوع ماج زيندر (MZI) المكون من مادة الليثيوم تنتلايت $LiTaO_3$ بواسطة اقتراح تقنية تخفيض الفجوة بين الأقطاب d . كذلك في هذه التقنية اقتراح نموذج رياضي لتحليل العوامل المؤثرة على التشابك الكهروضوئي مثلا" التغير الايجابي لمعامل الانكسار و طول الذراع للمفتاح الكهروبصري . في هذا البحث تم انجاز تشابك جيد بواسطة الحصول على تغير ايجابي لمعامل الانكسار كبير مع الحصول على طول ملائم لذراع المفتاح يصل الى 8 مايكرومتر مع قدرة تجهيز واطئة تصل الى 4 V/μm, كذلك بأستخدام مادة الليثيوم تنتلايت تم انجازكفائة افضل للنضام بأستخدام الاطوال الموجية تحت الحمراء.

1. Introduction

To plan and improve the waveguide of optical devices it is important to compute characteristics values, that characterized optical overlap (optical confinement factor), thus the reaction of light with the surround material [1]. The overall performance of a modulator depended linearity on the capability for the optical mode to overlap with the effective material (i.e., applied electric field on the material). A contrast of the modulation overall performance as a function of optical overlap[2]. The optical overlap, Γ, known as the portion of the optical field overlapping with the applied electric field on the material [3] and specifically, it appears how well the guided mode field is limited in a specific locale [1]. Thus, in silicon nitride-lithium niobate Si-LN optical device a small overlap establishes between apportion of the mode power and the lithium niobate LN region because of it supports a distributed optical mode within silicon nitride-lithium niobate Si/LN waveguide thus the

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modulation efficiency is low [4]. A large optical overlap achieved in the lithium niobate LN layer on insulator which improved as a better platform to plan waveguides [5-16]. In the electro-optic E-O polymer device the optical overlap depends on dimensions of the cavity and width of electrode such as in dimensions of 240 and 110 nm for width of electrode and cavity respectively, the optical overlap is great, otherwise in the case the width of electrodes and gap varied by ±30 nm, the optical overlap is reduced by3%, see figure (1) [17]. In the Silicone electro-optic devices, the optical overlap can be increased by fabricating optical devices with thicker hybrid barium titanate BTO, where by the fabricating optical devices support other a singular transverse electric TE-mode where the optical power confined in the layer of the electro-optic active barium titanate BTO by 18% [18].

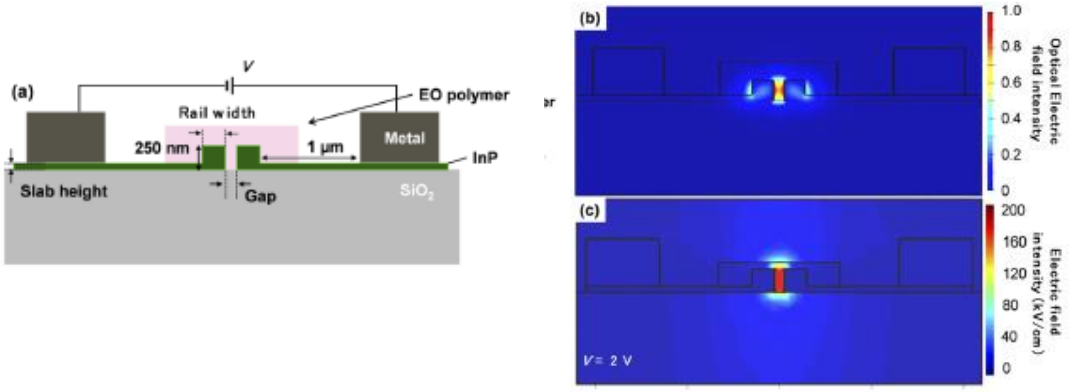

Figure (1): (a) Electro-optic polymer with cross section structure, (b) Distribution of optical electric field for slot mod of Inp slot waveguide, (c) Distribution of DC electrical field on waveguide of InP slot [17]

This paper introduces a model to solve a problem of overlap for length of arm with the ordinary positive changing index of refractive by applied of eclectic field. it utilizes a 2×2 Mach-Zehnder interferometer MZI electro-optic switch depends on electro-optic effect (Pockel effect) for $LiTaO_3$ as shown in Fig. 2 and Table 1.

Table (1): electro-optic coefficients (r33), refractive index (no) and wavelengths (λ), for $LiTaO_3$

*R33**(Pm/V)***	*Ordinary refractive index **no***	*Wavelength **(nm)***	*Ref.*
30.5 ± 0.3	*2.1763*	*632.8*	*[19]*
27.4 ± 0.3	*2.1186*	*1558*	*[19]*

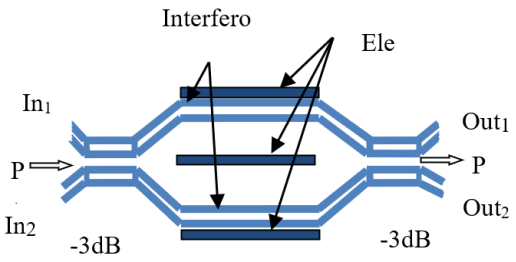

Figure (2): 2×2 Mach-Zehnder interferometer MZI electro-optic witch base on the electro-optic impact

In this system A Mach-Zehnder interferometer MZI consists of two branches of interferometer with equal length arm where the intensity of light it was modulated with phase difference Δϕ and applied electric field E. Addition a constructive of interference was happened because of the lengths of optical path for arm is same at result to recombined of optical waves on the end of arms switch whereupon:

$$I = I_o cos^2\left(\frac{\Delta\phi}{2}\right) \quad \ldots(1)$$

$$E = E_o e^{i(Kx-wt)} \quad \ldots(2)$$

$$E = E_o \cos\left(\frac{\Delta\phi}{2}\right) e^{i(Kx-wt)} \quad \ldots(3)$$

Therefore, when applied electric field a long of optical axis of crystal material the refractive index changes, as shown in Fig. (3) whereupon [20].

$$\Delta n_X = \frac{1}{2} n_X^3 r_{33} E \quad \ldots(4)$$

Where r_{33} is electro-optic coefficient and n_x is refractive index in the x-direction. In addition, it employs a crystal material and a suitable polarizer as shown in Fig. 3 a phase modulated can be induced without modified in intensity or polarization thus, a drive voltage rotates the main optic axis in the cross section of crystal. The switching voltage is on/off when a polarizer puts in the parallel shape to only one of the main optic axes. Therefore, the input electrical-optical field in direction of x and the output optical wave whereupon [20]:

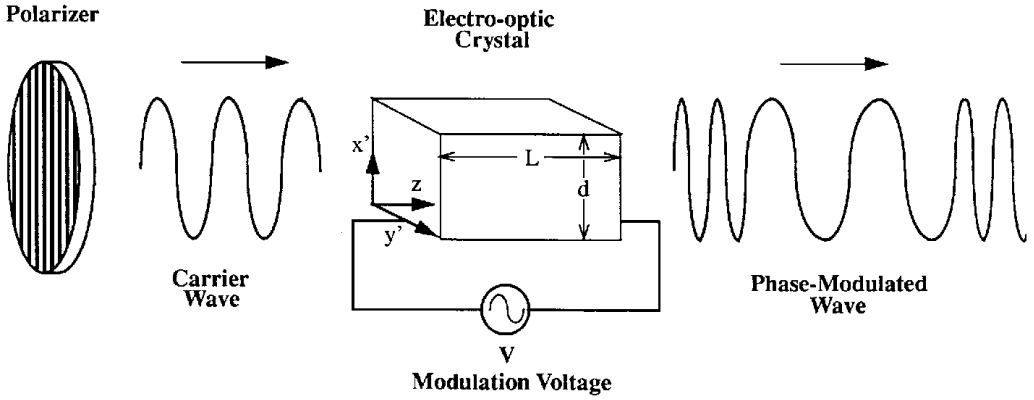

Figure (3): Applied an electrical field on the electro-optic crystal

$$E_i(t) = E_i \cos wt \quad \ldots(5)$$

$$E_o(t) = E_i \cos(wt - \phi) \quad \ldots(6)$$

Thus,

$$\emptyset = \frac{2\pi}{\lambda}(n_x - \Delta n_x)L = \phi_o + \Delta\phi_x \quad \ldots(7)$$

The expression of $\emptyset$ considered a totality phase shift included the ordinary phase term ϕ_o, L is length of crystal, and $\Delta\phi_x$ is electrically changing phase as [20].

$$\Delta\phi_x = \frac{2\pi L \Delta n_x}{\lambda} \quad \ldots(8)$$

Where the half-wave voltage switching voltage Vπ is :

$$V\pi = \frac{d\lambda}{L r_{33} n_o^3} \quad \ldots(9)$$

Where d is the waveguide gab in μm.

2. Analytical switch

The equation of the optical switch, in which the event light separates in two branches (Io1 and Io2), and an optical path will combine on the end of switch as (I_2 =Io1+ Io2), also, I_1 represents electro-optic output power. in this case:

$$\frac{2I_1}{I_2} = 2E[(E-1) + (1-E)\cos\Delta\emptyset] + 1 \quad \ldots(10)$$

An electro-optic switch will drive by applied an electric field on the arm as known in equation (2).

$$E = \frac{2\Delta n}{r_{33}\Gamma n_o^3} \quad \ldots(11)$$

Where electric field $E = \frac{V}{d}$ $in\ V/\mu m$, and Γ is optical overlap (unit less).

$$Y = \left(\frac{2\Delta n}{r_{33}\Gamma n_o^3} - 1\right) + \left(1 - \frac{2\Delta n}{r_{33}\Gamma n_o^3}\right)\cos\Delta\emptyset$$

$$= \frac{2\Delta n - r_{33}\Gamma n_o^3}{r_{33}\Gamma n_o^3} + \frac{(r_{33}\Gamma n_o^3 - 2\Delta n)}{r_{33}\Gamma n_o^3}\cos\Delta\emptyset$$

$$\frac{2I_1}{I_2} = \frac{4\Delta n}{r_{33}\Gamma n_o^3} Y + 1$$

$$M = (4\Delta n r_{33}\Gamma n_o^3 - 8\Delta n^2)\cos\Delta\emptyset$$

$$Z = \frac{8\Delta n^2 + 4\Delta n r_{33}\Gamma n_o^3 + M}{r_{33}^2\Gamma^2 n_o^6}$$

$$\frac{2I_1}{I_2} = Z + 1$$

$$\frac{2I_1}{I_2} = \frac{r_{33}^2\Gamma^2 n_o^6 + 8\Delta_n^2 + 4\Delta n r_{33}\Gamma n_o^3 + M}{r_{33}^2\Gamma^2 n_o^6}$$

$$I_2(r_{33}^2\Gamma^2 n_o^6 + 8\Delta n^2 + 4\Delta n r_{33}\Gamma n_o^3 + M) = 2I_1 r_{33}^2\Gamma^2 n_o^6$$

$$N = 2I_1 r_{33}^2\Gamma^2 n_o^6 - I_2 r_{33}^2\Gamma^2 n_o^6 - 8\Delta_n^2 I_2 - 4\Delta n I_2 r_{33}\Gamma n_o^3$$

$$I_2 M = N$$

$$\cos\Delta\emptyset = \frac{N}{I_2(4\Delta n r_{33}\Gamma n_o^3 - 8\Delta n^2)}$$

$$\cos\Delta\emptyset = \frac{(2I_1 - I_2)r_{33}^2\Gamma^2 n_o^6}{I_2(4\Delta n r_{33}\Gamma n_o^3 - 8\Delta n^2)} + 1 \quad \ldots(12)$$

$$\cos\Delta\emptyset - 1 = \frac{(2I_1 - I_2)r_{33}^2\Gamma^2 n_o^6}{I_2(4\Delta n r_{33}\Gamma n_o^3 - 8\Delta n^2)} \quad \ldots(13)$$

$$B = 4I_2\Delta n r_{33}\Gamma n_o^3 \cos\Delta\emptyset - 4I_2\Delta n r_{33}\Gamma n_o^3 - 8\Delta n^2\cos\Delta\emptyset + 8\Delta n^2$$

$$B = (2I_1 - I_2)r_{33}^2\Gamma^2 n_o^6$$

$$F = \Delta n(4I_2 r_{33}\Gamma n_o^3 \cos\Delta\emptyset - 4I_2 r_{33}\Gamma n_o^3) + r_{33}^2\Gamma^2 n_o^6(I_2 - 2I_1)$$

$$\Delta n^2(8 - 8\cos\Delta\emptyset) + F = 0$$

$$\because \Delta\phi = \frac{\pi L n_o^3 r_{33} V}{\lambda d} \quad \ldots(14)$$

$$\Delta n = \frac{-(4I_2 r_{33}\Gamma n_o^3 \cos\Delta\emptyset - 4I_2 r_{33}\Gamma n_o^3) \pm J}{16(1 - \cos\Delta\emptyset)} \quad \ldots(15)$$

$$J = \sqrt[2]{(4I_2 r_{33}\Gamma n_o^3 \cos\Delta\emptyset - 4I_2 r_{33}\Gamma n_o^3)^2 - 4(I_2 - 2I_1)r_{33}^2\Gamma^2 n_o^6(8 - 8\cos\Delta\emptyset)}$$

3. Results and discussions:

This study suggests a model for propose a type of optical device a 2×2 Mach-Zehnder interferometer electro-optical switch base on lithium tantalite $LiTaO_3$ when an overlap is important factor for enhancement the performance of electro-optic switch. Also, the electro-optic effect (Pockel effect) is useful, where the performance of switch will evaluate using the equation.15. In this paper, the type of device configuration is transverse where the voltage applied perpendicular to the direction of propagation, thus, the gap between electrodes d acts as capacitor in

which d restricts the speed of MZI electro-optic switch (i.e., the speed of switching), addition, the electric field because E = V/d, therefore, the reduction of d creates the electric field E increases, thus, the ordinary positive refractive index changes Δn will rise, also, the Δn will inversely proportional to the gap between electrodes d as equation(11), therefore, the reduction of d results to large overlap because of the Δn is large, also, in the case transvers configuration the aspect ratio L/d is very large because of the electrodes not restricted the passing of optical light through arms of switch, thus the aspect ratio effective factor to be induced phase shift because the large aspect ratio due to small induced phase shift and vice versa, then, it will result the high quality switching, better modulation, and large overlap. Also, in the case it applies electric field about 4V/μm, the ordinary positive refractive index changes and considers very low power consumption, thus, the better performance for switch achieves also, the overlap is large which depends on the gap between electrodes d, length of arms L, and the ordinary positive refractive index change Δn, so it must be choose an appropriate length for arm that relative to a large applied of electric field, with the small d therefore, when the arm about 8μm with larger ordinary positive changing of refractive index Δn, the overlap is better , as shown in Figs. 4 and 5. In addition, the small refractive index n_o and electro-optic coefficient r_{33} leads to large overlap, therefore, these factors are inversely proportional to the overlap Γ as equation(11), thus. the positive changing of refractive index and length of arm are large these, result a better overlap by limited the n_o and r_{33}, as shown in Figs. 6 & 7. Also, the operating wavelengths improve the performance of electro-optic switch with applying electric field because, it uses wide band of wavelength thus, the ordinary positive changing of refractive index is better, as shown in Fig. 8.

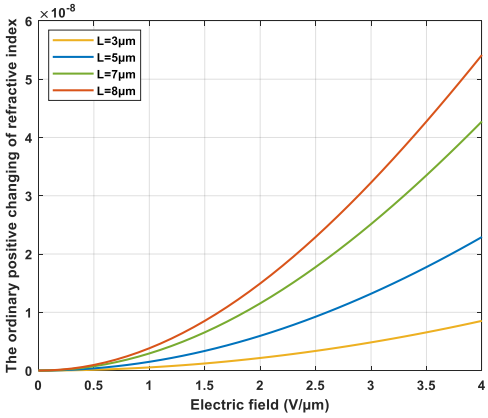

Figure (4): The ordinary positive changing of refractive index by applying electrical field with different length of arms

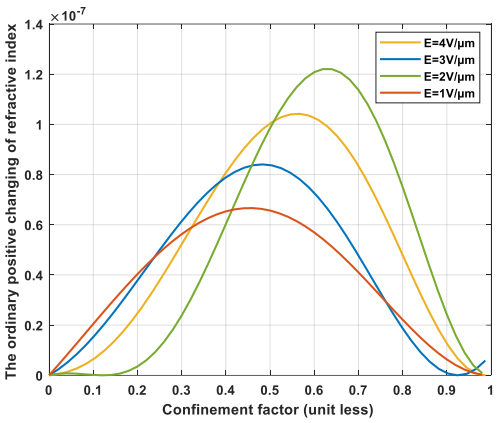

Figure (5): The ordinary positive changing of refractive index as a function of confinement factor with different applying electrical field

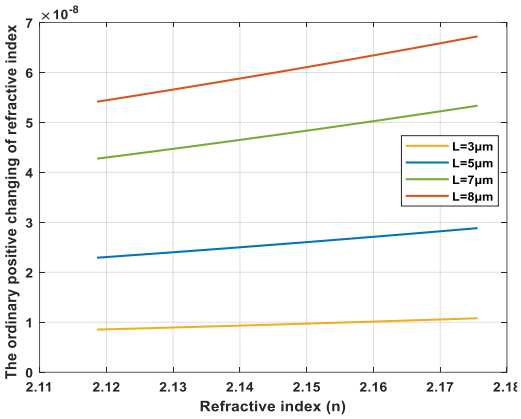

Figure (6): The ordinary positive changing of refractive index as a function of refractive index with different length of arms for $LiTaO_3$

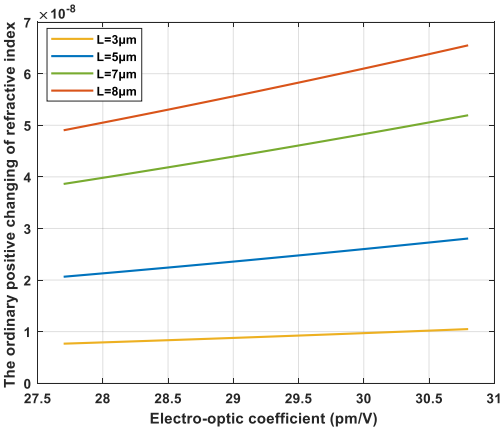

Figure (7): The ordinary positive changing of electro-optic coefficient as a function of electro-optic coefficient with different length of arms for $LiTaO_3$

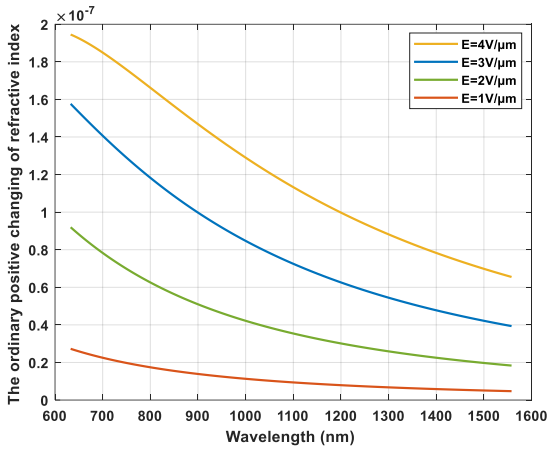

Figure (8): The ordinary positive changing of refractive index with wavelength and different applying electrical field for $LiTaO_3$

4. Conclusions

This study proposes model for enhancement of a 2×2 Mach-Zehnder interferometer optical switch for lithium tantalite $LiTaO_3$, which base on electro-optic effect (Pockels effect). This research improves the performance of switch by reduction of gap between the electrodes d, thus it achieves a high quality overlap, and this is by a large positive changing of refractive index with better small length about 8μm, and low driving power electric field at least 4V/μm. In addition, for lithium tantalite $LiTaO_3$, it uses a wide band of wavelengths therefore, it improves the performance of electro-optic switch.

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