DEVELOPMENT OF AN OPTICAL PULSING BY USING POCKELS EFFECT

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To my beloved parents,
brother and sisters

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ABSTRACT

Laser produced from active medium is normally in continuous mode. The beam can be modulated by inserting switching mechanism. An electro-optic mechanism is one of the techniques used to alter the operation of laser beam from continuous into pulse mode. Hence, the objective of this project is to develop an optical switch system by using Pockels effect. Helium-Neon (He-Ne) laser was used as continuous light source in the project. Calcite and quartz crystals were employed as natural birefringent materials. While a synthetic birefringent material, lithium niobate was used as a Pockels cell. The lithium niobate crystal can become birefringent only through the application of electric field. Therefore, several pulse generators were developed and used to trigger an electro-optic driver to electrify the lithium niobate crystal. A Pockels cell house was designed and fabricated by using perspex. The Pockels cell house was completed with electrodes. The performance of the fabricated Pockels cell was compared to the commercial Pockels cell. Both of the Pockels cells exhibited similar characteristic, whereby the linear polarization state of laser light was turned into circular state when it entered the electrified Pockels cells with $a : b$ ratio of 1.0 : 1.0 (2 kV and 3 kV voltage applied) and 1.1 : 1.0 (4 kV voltage applied). This converts the continuous He-Ne beam into pulse mode. The generation of the laser pulse can be operated either in a single or repetitive mode. It depends on the frequency of the pulse generator. The amplitude of the produced laser pulse was increased by increasing the voltage supplied to electrify the lithium niobate crystal. The amplitude of the produced laser pulse by using transverse Pockels cell was 500 mV, 700 mV and 1000 mV at 2 kV, 3 kV and 4 kV applied voltage. While the result obtained by using commercial Pockels cell was 700 mV, 900mV and 1200 mV.

ABSTRAK

Laser yang dihasilkan daripada medium aktif biasanya diperoleh dalam bentuk selanjar. Alur ini boleh dimodulasi dengan memasukkan mekanisma pensuisan. Mekanisma elektro-optik adalah salah satu teknik yang digunakan dalam pensuisan laser selanjar kepada denyut. Tujuan projek ini adalah untuk menghasilkan satu sistem pensuisan cahaya dengan menggunakan kesan Pockels. Laser Helium-Neon (He-Ne) digunakan sebagai sumber cahaya selanjar dalam projek ini. Hablur kalsit dan kuartz digunakan sebagai bahan dwibiasan semulajadi. Manakala *lithium niobate* (bahan dwibiasan buatan) digunakan sebagai sel Pockels. *Lithium niobate* hanya akan menjadi bahan dwibiasan apabila dikenakan medan elektrik. Beberapa penjana denyut dibina dan digunakan untuk membekalkan medan elektrik kepada *lithium niobate*. Rumah sel Pockels direka dan dibina dengan menggunakan perspek. Rumah ini dilengkapkan dengan elektrod. Prestasi sel Pockels yang dibina dibandingkan dengan sel Pockels komersial. Kedua-dua sel Pockels menunjukkan sifat sama dengan menukarkan pengutuban linear cahaya laser kepada bulat dengan *a : b* 1.0 : 1.0 (bekalan elektrik 2 kV dan 3 kV) dan 1.1 : 1.0 (bekalan elektrik 4 kV) apabila laser dilintaskan melalui sel Pockels yang dikenakan elektrik. Keadaan ini menyebabkan operasi He-Ne laser selanjar bertukar kepada denyut. Laser denyut yang dijanakan boleh dalam bentuk tunggal atau berulang-ulang. Penjanaan laser denyut bergantung kepada frekuensi penjana denyut. Amplitud laser denyut yang dihasilkan bertambah dengan penambahan bekalan elektrik pada *lithium niobate.* Amplitud laser denyut yang dihasilkan (sel Pockels yang dibina) adalah 500 mV, 700 mV dan 1000 mV pada bekalan elektrik 2 kV, 3 kV dan 4 kV. Manakala untuk sel Pockels kommersial adalah 700 mV, 900 mV dan 1200 mV.

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LIST OF SYMBOLS

a	-	Amplitude of the light component A_1
A_o	-	Amplitude of the transmitted light
A_1	-	Amplitude of the light component
A_2	-	Amplitude of the light component
A_s	-	Total amplitude of the light
B	-	Pulse width
C	-	Capacitance
b	-	Amplitude of the light component A_2
d	-	Width of the crystal
E	-	Electric vector
EO	-	Extraordinary beam
f	-	Frequency
F	-	Focal length
H	-	Magnetic vector
I	-	Intensity of the transmitted electromagnetic or mechanical waves
I	-	Intensity of the He-Ne light
I_o	-	Intensity of the incident light
i	-	Current
k	-	Multiple factor
$\boldsymbol{k}$	-	Wave vector of the light wave
K_{PD}	-	Responsivity of the photodiode
l	-	Length of the crystal
n_e	-	Refraction index of the extraordinary beam

n_o	-	Refraction index of the ordinary beam
Δn	-	Birefringence or double refraction
M	-	Slope of the graph
O	-	Ordinary beam
P	-	Light power
P_1	-	Polarizer
P_2	-	Analyzer
Q	-	Quartz crystal
r	-	Electro-optic coefficient
R	-	Resistance
t	-	Period
V	-	Applied voltage
Va	-	Average voltage
V_{in}	-	Supplied voltage
z	-	Optical axis
λ	-	Wavelength of the light
θ	-	Angle of the analyzer
$\Delta\phi$	-	Phase retardation

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CHAPTER 1

INTRODUCTION

1.1 Light Modulation

Applications of laser light always require the modulation of some properties of the laser light wave. The modulation of light wave is to control variation of some detectable properties of the light wave, such as its intensity (amplitude), phase, wavelength (frequency) or polarization (direction of the beam propagation) (Schawlow, 1969; Hammer, 1975). A modulator is a device that alters a detectable property of a light wave corresponding to an applied electric signal (Hammer, 1975).

Actually there are a number of methods which can be used to modulate laser light such as mechanical, electro-optic, magneto-optic and acousto-optic. Most mechanical methods such as rotating mirror and mechanical shutter or chopper used for laser-beam modulation are slow, unreliable and have much inertia to allow the faster light modulation (Kaminow and Turner, 1966; Schawlow, 1969). Thus, the mechanical methods are seldom used in modern modulation equipment. Hence, the interaction between laser wave and electric, magnetic or acoustic fields acting through the electro-optic, magneto-optic and acousto-optic effect are used to modulate laser-beam (Kaminow and Turner, 1966; Chen, 1970). Modulation of laser-beam by using these effects is faster and more reliable than the mechanical methods. Among these three interactions, electro-optic effect has received most attention and is widely used for light modulation as it provides the fastest modulation (Schawlow, 1969; Booth and Hill, 1998). For electro-optic effect, the application of an electric field across certain crystal is used to result in change of refraction index of the crystal. The crystal becomes birefringent under the influence of the applied electric field (O'Konski, 1978; Noriah Bidin, 2003). These crystals include, potassium dihydrogen phosphate (KDP), potassium dideuterium phosphate (KD*P), lithium niobate ($LiNbO_3$), lithium tantalite ($LiTaO_3$) and cesium dihydrogen arsenate (CDA) (Kuhn, 1998).

The electro-optic effect can be used to control the intensity or phase of the propagating light (Yariv, 1997). The modulation by using electro-optic effect is the basic operation concept for the optical modulator, optical switch, Q-switch, and deflector (Zajac, 1982; Laud, 1985; Chuang, 1996).

1.2 The History Of Electro-optic

In 1875, Kerr observed that certain dielectric medium become doubly refractive when placed in a strong electric field (Schawlow, 1969; Kaminow, 1974). This effect was consequently named as Kerr effect, or quadratic electro-optic effect. He also discovered this effect in liquids such as carbon disulphide (Kaminow and Turner, 1966; Camatini, 1973; Kaminow, 1974). The Kerr effect can be observed in any crystal (Schawlow, 1969).

The linear electro-optic effect was introduced by Pockels in 1893 (Jenkins, and White, 1976). The linear electro-optic effect is always called as Pockels effect to distinguish it from Kerr effect. This effect can occur only in crystals that lack of a center of symmetry (Schawlow, 1969). During the nineteenth century, Pockels examined the Pockels effect in quartz, tourmaline, sodium chlorate and K-Na tartrate salt (Rochelle salt) (Kaminow and Turner, 1966).

1.3 Research Background

The first useful Pockels cell was made of potassium dihydrogen phosphate (KDP) by Billings in 1949. However, this device was not capable to be used for high-frequency operation. In 1961, Schawlow, developed a high frequency laser modulator made of KDP crystal based on the Pockels effect. But, the power required was too high for practical use. This stimulated interest of many researchers in searching other feasible crystals (Kaminow, 1974).

Since then, lithium niobate ($LiNbO_3$), lithium tantalite ($LiTaO_3$) and ammonium dihydrogen phosphate (ADP) are a few more capable materials used for light modulation (Schawlow, 1969). In 1967, Kaminow and his group constructed light intensity modulators by using $LiTaO_3$ and $LiNbO_3$. The performance of the $LiNbO_3$ intensity modulator has of slight advantage compared to the $LiTaO_3$ due to the larger electro-optic coefficient of $LiNbO_3$. Light modulation by using Pockels effect on $LiNbO_3$, KDP and ADP was well established (White and Chin, 1972; Salvestrini *et al.*, 2004).

A few forms of modulator have been developed by using Pockels effect. They are lumped, traveling wave, zigzag, and optical waveguide modulator. The configuration of each type of modulator has been described by Chen (1970). The physical construction of each modulator is illustrated in Figure 1.1, 1.2, 1.3 and 1.4 (Chen, 1970). Among them, lumped modulator is most suitable to be used for modulation of frequency < 1 GHz and with the crystal length about 1 cm. Traveling-wave and zigzag modulator are used for modulation of frequencies greater than 1 GHz (Denton *et al,* 1967). The type of modulator chosen depends on the required driving power and crystal length (Chen, 1970).

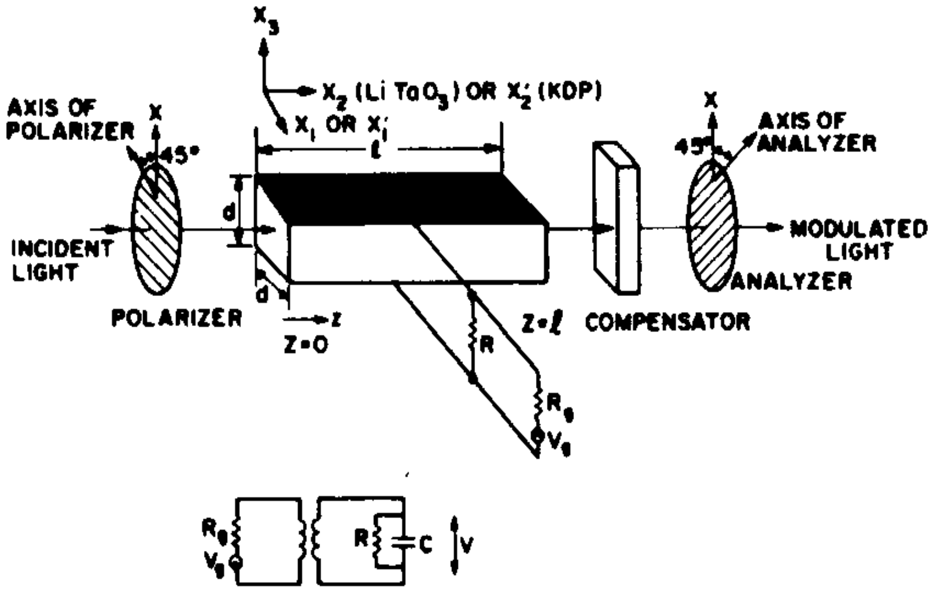

Figure 1.1: Lumped modulator and its electric circuit (Chen, 1970)

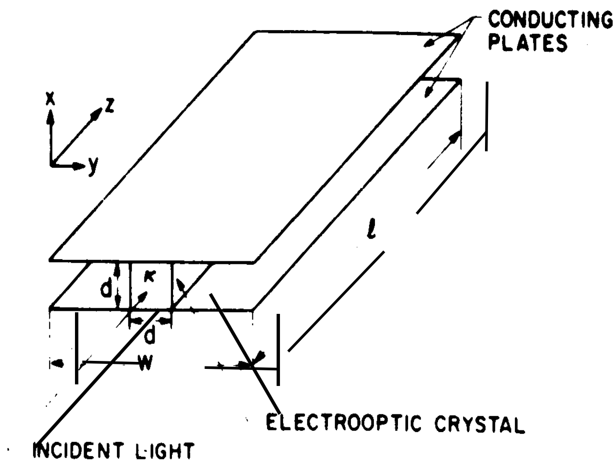

Figure 1.2: Traveling-wave modulator using two-plate structure (Chen, 1970)

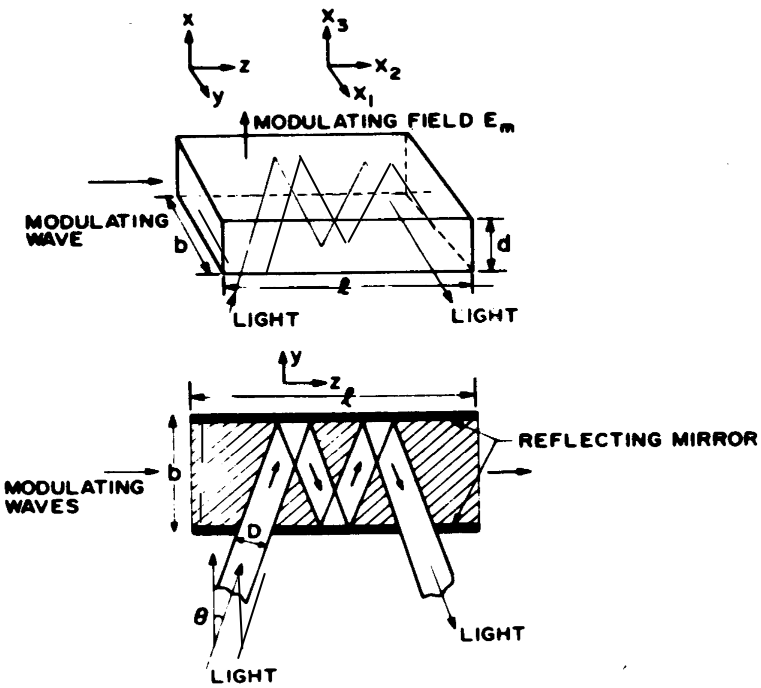

Figure 1.3: Zigzag modulator (Chen, 1970)

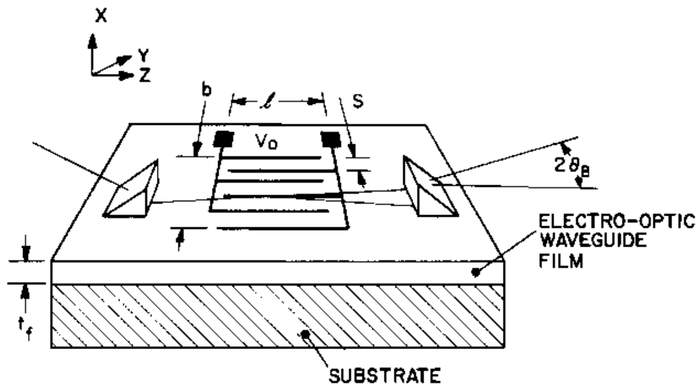

Figure 1.4: Optical waveguide modulator (Hammer, 1975)

A lumped electro-optic optical modulator has been developed by using single crystal $LiTaO_3$ which is in a cylinder form. A transistor driver-amplifier with a 0.2 W output power is used to drive the $LiTaO_3$ at a light wavelength of 632.8 nm In order to reduce the voltage for modulation, the modulator is configured in the transverse mode. The modulator provides 40% intensity of modulation (Kaminow and Sharpless, 1967).

The accurate and direct determination of the phase retardation due to the birefringence of certain materials can be done by using a technique based on the linear variation of the transmitted intensity with the applied electric field to an amplitude modulator (O'Shea, 1985).

1.4 Comparison Between Different Techniques Of Beam Modulation

Besides the Pockels (linear electro-optic) effect, other techniques like magneto-optic, acousto-optic and Kerr effects can also be used to change the refraction index of an optical medium through the application of an external field. However the Pockels (linear electro-optic) effect is chosen because of some advantages. The comparison between different techniques of laser beam modulation is listed in Table 1.1.

Table 1.1: Comparison between different modulation techniques

Techniques	Advantages	Disadvantages
1. Pockels (linear electro-optic) effect	- Fastest modulation speed (Schawlow, 1969; Booth and Hill, 1998; O'Shea, 1985). - Easy electric field generation (Booth and Hill, 1998). - Precise timing.	- Expensive. - Only occur in the 21 types of crystal classes (Bessley, 1976; Noriah Bidin, 2003). - Required large voltage. - To get good result need high quality polarizer (Booth and Hill, 1998).
2. Kerr effect	- Occur in all the 32 types of crystal classes (Bessley, 1976).	- Kerr coefficient of most crystals is small. - Nitrobenzene with high Kerr coefficient is toxic and unstable (Bessley, 1976). - Required higher voltage than Pockels effect (Lothian, 1975).
3. Acoustic effect	- Simple radio frequency circuit.	- Slow opening times (Booth and Hill, 1998)
4. Magneto effect	- Applied to gases, liquids and solids (Bessley, 1976).	- Slow opening times. - Hard to generate require magnetic strength (Bessley, 1976).

There are many techniques that can be used to modulate the laser beam by changing the refraction index of an optical medium. But electro-optic promises a better offer than the rest. It can be used either as an internal or external modulator (Bessley, 1976).

In this project, Pockels effect has been applied to produce an optical switch. It is an important element in the construction of a Q-switched Nd:YAG laser for medical purpose.

1.5 Research Objectives

The objectives of this research are listed as followed:

1. To diagnose birefringence characteristic,
2. To design a trigger system,
3. To develop a Pockels cell and
4. To characterize the output of an optical switch.

1.6 Scopes of Research

In this research, the polarization of He-Ne light was analyzed by using Malus' Law. Natural birefringent materials, like quartz and calcite crystal were used as specimen.

A transverse Pockels cell was developed by applying electric field across the lithium niobate crystal. High voltage was supplied to Pockels cell. A pulse generator was designed to trigger the switch in single mode and repetitive mode.

1.7 Organization of Thesis

This thesis consists of seven chapters. The introduction, research background, objectives and scopes of research are briefly mentioned in Chapter 1. Chapter 2 describes some important theories that are related to optical switch. Chapter 3 discusses about the optical and electrical equipments used to accomplish the project. The development of the pulse generator used to trigger the electro-optic driver is discussed in Chapter 4. Chapter 5 describes about the preliminary works on natural birefringent materials. The development of a transverse Pockels cell and it diagnostic will be discussed in Chapter 6. The application of Pockels cell as an optical switch is elaborated in Chapter 7. Finally, the conclusions of this research, research problems and suggestions are in Chapter 8.

dimension and the material of the electrodes in the transverse Pockels cell were not suitable to produce a strong electric field to the crystal.

The CD4528BCN dual monostable multivibrator used was very sensitive. The operation of single and repetitive mode pulse generator could not be combined. Therefore, two types of pulse generator were developed.

8.3 Suggestions

The project should be continued for further studies by packaging or combining all the separate components like pulse generator, power supply, electro-optic driver and Pockels cell to become a complete optical switch system.

In order to use this system as a Q-switch system for high power laser, the Pockels cell should be provided with a temperature controller to avoid overheating, which will damage the crystal during switching.

It is also suggested that an interlocking system should be installed in this system to avoid any accident, by switching off the system immediately whenever overheating occurs.

Further studies can also be carried out to determine the most suitable material, dimension and method to produce a better electrode.

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