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Diagnostic of High-Energy Nd-YAG Laser Polarizer

(Diagnosis Pengkutub Laser Nd-YAG Berkuasa Tinggi)

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Abstract

Polarized beam is very vital for operating light switches. High polarization purity is pertinent in high power Q-Switched Nd:YAG laser system. The aim of this project is to diagnose two high-energy polarizers which are commonly used in Q-Switched Nd:YAG laser system namely Glenn-Laser calcite and thin film. The polarization purity was determined by using low power He-Ne laser in place of high power Nd:YAG. The power of He-Ne laser was set at 10 mW with wavelength of 632.8 nm. The beam was aligned to produce parallel plane polarizer. A polaroid polarizer was used as analyzer. The transmission power was measured using a power meter at variable angular rotations from 0^0 to 360^o. The result obtained shows that, both polarizers have produced linear polarization. However, the thin film polarizer had produced a closer result more similar to He-Ne beam polarization. Hence, the thin film polarizer is a better choice to polarize high power Nd:YAG beam since it has higher polarization purity and transmission.

Keywords: High power Nd:YAG laser, high energy polarizer, linear polarization.

Abstrak

Sinar terkutub sangat penting untuk operasi pensuisan cahaya. Ketulenan pengkutuban yang tinggi sangat penting untuk sistem laser Nd:YAG berkuasa tinggi dengan suis-Q. Matlamat projek ini adalah untuk mendiagnosis dua pengkutub bertenaga tinggi yang biasa digunakan dalam sistem laser Nd:YAG dengan suis-Q iaitu kalsit Glenn-Laser dan saput tipis. Ketulenan pengutuban ditentukan menggunakan laser He-Ne berkuasa rendah bagi menggantikan laser

Nd:YAG berkuasa tinggi. Kuasa laser He-Ne ditetapkan pada 10 mW dengan panjang gelombang 632.8 nm. Alur sinar dijajarkan untuk menghasilkan satah pengkutub selari. Pengkutub polaroid pula digunakan sebagai penganalisis. Kuasa penghantaran diukur menggunakan meter kuasa pada pelbagai sudut putaran dari 0^0 hingga 360^o. Keputusan yang diperolehi menunjukkan kedua-dua pengkutub menghasilkan pengkutuban linear. Walau bagaimanapun pengkutub saput tipis telah menghasilkan keputusan yang lebih menyerupai pengkutuban sinar He-Ne. Oleh itu, pengkutub saput tipis merupakan pilihan yang lebih baik untuk mengkutubkan sinar Nd:YAG berkuasa tinggi kerana memiliki ketulenan dan penghantaran pengkutuban yang lebih tinggi.

Kata kunci: Laser Nd:YAG berkuasa tinggi, pengkutub tenaga tinggi, pengkutuban linear.

Introduction

The electro-optic effect can be used to control the intensity of phase of the propagating light (Yariv, 1994). The modulation by using electro-optic effect is the basic operation concept for the optical modulator, optical switch, Q-switch and deflector (Chuang, 1996 & Thian, 2004). There are two types of electro-optic effect, namely, quadratic electro-optic which also refers as Kerr effect and linear electro-optic effect or known as Pockels Effect (Noriah, 2002). Light modulation by using Pockels Effect on birefringence material like $LiNbO_3$, KDP and ADP was well established (Salvestrini et al., 2004). Basically the modulation occurs due to the change of refraction index after applying an electric field. Beside the need of external force, the most crucial is the optical properties of birefringence material and it can only be manipulated by applying polarized light. Hence the fundamental concept of the polarization state of the light is pertinent in developing the optical switch. Therefore, this paper is intended to study the polarization state and purity on two polarizers commonly used in high-power Nd-YAG laser.

Theory

Laser emits coherent electromagnetic radiation field (Yariv & Yeh, 1984). An electromagnetic field in free space can be described by its vectors; electric, **E** and magnetic, **H**, that vibrate perpendicularly to each other as shown in Figure 1.

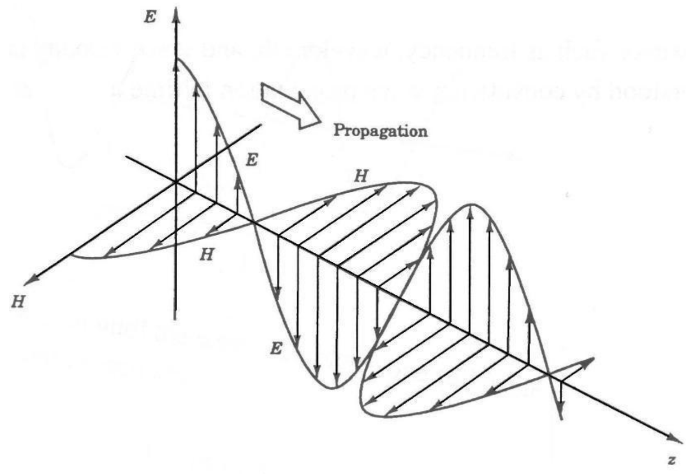

Figure 1 An electromagnetic wave

The interaction between a light (electromagnet wave) and matter involves redistribution of the charges on its molecules. It is predominantly influenced by the electric vector rather than the magnetic vector (Jenkins & White 1976, Klinger et al., 1990). Therefore further discussion will emphasize more on the electric vector.

Light wave can be polarized by using a polarizer (Rahim, 1996). Polarized light carries valuable information about the various physical parameters that have been acting on it. Magnetic fields, chemical interaction, molecular structure and mechanical stress all affect the optical polarization. Applications relying on these polarization change including, light switching, electric power generation and certain niches in molecular biology.

Polarization states could be linear, circular or elliptical with respect to the path traced by electric field vectors in a propagating wave train (Hetch & Zajac, 1982) as shown in Figure 2. The intensity and polarization state can be determined by Malus's Law (Jenkins et al., 1976) given in Equation 1:

$$I = A^2 \cos^2 \theta \qquad (1)$$

Where I, is the intensity of light transmitted from polarizer, A is the amplitude and θ, is the angle between analyzer axis and polarizer axis. When light strikes the analyzer with an angle θ, only the light with its vibration parallel to the axis of the analyzer is allowed to pass through.

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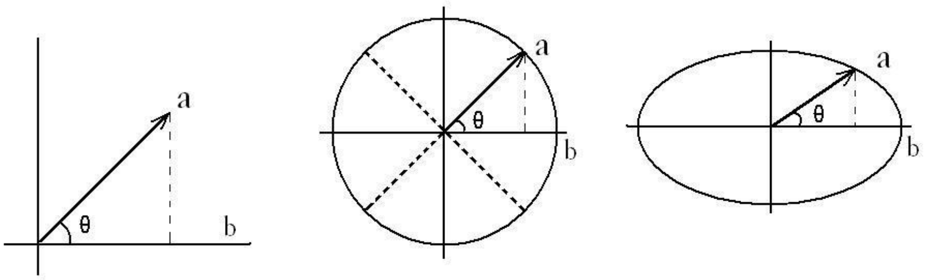
(a) Linear state (b) Circular state (c) Elliptical state



a = Analyzer axis, b = Polarizer axis

Figure 2 Polarization states

In general, the amplitude of the wave can be derived as:

$$A^2 = a^2 \cos^2 \theta + b^2 \sin^2 \theta \qquad (2)$$

And for a linear polarization state where b = 0, Equation 2 become:

$$I = A^2 = a^2 \cos^2 \theta = I_0 \cos^2 \theta \qquad (3)$$

However, when a > b or b > a; Equation 2 can be rewritten as:

$$I = (a^2 - b^2) \cos^2 \theta \ + \ b^2 \qquad (4)$$

Equation 4 is a linear equation which can be compared to a general linear equation Y = mx + C; where m, is the gradient of the slope and c, is an interception on y axis of the graph.

Methodology

In this study, two types of polarizer were employed, namely Glenn-laser calcite polarizer and thin film polarizer. The selections of these two polarizers are due to the requirement to have extreme polarization purity and high resistance to laser damage. This could be the demanding application for Nd-YAG laser in the future. Glenn-laser polarizer is made of air-spaced selected grade calcite prism. Calcite is a natural birefringence crystal which will divide an entering beam of laser light into two beams having opposite polarization. In Glenn type polarizer, one of the polarization planes is being eliminated. The Glenn polarizer housing contains two escape parts to provide an exit for the rejected polarization component. These windows also function to avoid dangerous laser absorption. This allows Glenn polarizer to be used in Q-switched laser cavity. Damage threshold for this polarizer is 4 J/cm^2 with 10 nanosecond pulses.

Another polarizer utilized in this study was thin film type. The polarizer coating have been optimized specially to be used with Nd-YAG laser. The thin films are coated on high quality BK7 substrate which could afford to have minimal wavefront distortion and a damage threshold exceeding 5 J/cm^2. The configuration of the high power polarizer is rectangular, with 14.3 mm x 28.6 mm dimension. It was mounted at Brewster's angle in the polarizer housing. In order to achieve maximum transmission, the polarizer was provided with angular tuning feature.

Although both polarizers are intended to be used with high power Nd-YAG laser, for testing the optical polarization however, lower power continuous wave He-Ne laser have been utilized. The power of the laser was 10 mW with wavelength of 632.8 nm. Before applying this beam as illumination source, the plane polarization was first identified. This is achieved by aligning the beam using Brewster method. The beam was adjusted until the minimum reflection beam was measured at Brewster angle of a glass plate. This indicated that the direction of polarization of the beam is parallel to the incident plane of the glass. Pure polarization of He-Ne was obtained by using only Polaroid analyzer, without any polarizer. The parallel polarization of the He-Ne beam was then utilized for testing the transmission and the state of polarizer of the tested polarizer.

Melles Griot 3-Watt Broadband power/energy meter was employed to measure the transmission power. A Polaroid material was used as an analyzer. The parallel polarization beam of He-Ne laser was then illuminated on each of the polarizer. The transmission power was measured by rotating the angle of analyzer from 0^0 to 360^o with the increment of 15^o. The experimental setup is shown in Figure 3.

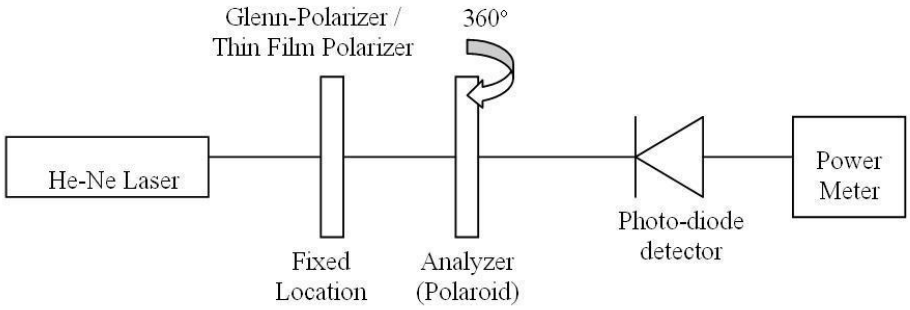


Figure 3 Setup for testing the polarization purity and state of high-energy polarizer

Result and Discusssion

The result obtained from this experiment is represented in a graph shown in Figure 4. The transmission powers measured without polarizer and from both polarizers are plotted against the angle of analyzer. The configurations of these curves are almost similar. However, the graph from thin film polarizer was found to be slightly higher compared to the results obtained form Glenn-laser polarizer. Without polarizer, the transmitted power of He-Ne was the highest among all. This is because the incident beam was transmitted directly without passing through any glasses. All graphs indicate that, the maximum transmission occur at 0^o, 180^o and 360^o, while minimum transmission occur at 90^o and 270^o. The profile of He-Ne laser is used as a reference or indicator for plane polarization

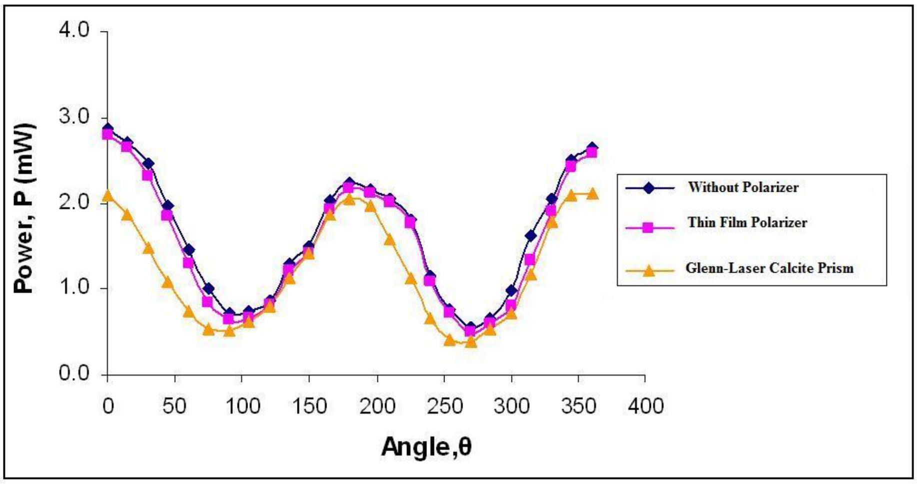


Figure 4 The polarization profile of He-Ne beam

The polarization state was determined by plotting the power transmission against $\cos^2\theta$. The graphs obtained are shown in Figure 5. Straight line graphs were obtained that indicate that the power and consequently the intensity of the beam is proportional to $\cos^2\theta$, which obeys the Malus's Law (Refer Equation 1).

However, the graph interception on the axis of transmission power is at (0, 0.41) for Glenn-laser polarizer and (0, 0.71) for thin film polarizer, when the graph should intercepts at (0, 0) for a linear polarization state, i.e when b=0 (Equation 4). These results were compared with the linear polarization of He-Ne without any polarizer, where the graph interception is at (0, 0.85), when $b \neq 0$. There will be no real pair of polarizer and analyzer that can totally extinguish an incident beam when they crossed (Klinger et al., 1990). These results show that, the states of polarization after passing through both polarizers are linearly polarized.

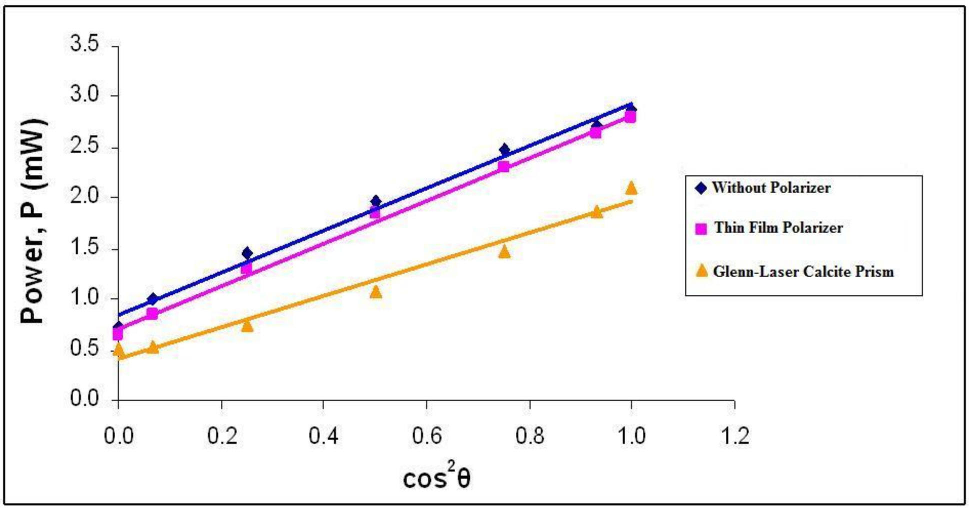


Figure 5 The polarization state of He-Ne beam

The obtainable of linear polarization confirm that, both types of polarizers are capable in inducing the purity of polarization. The purity of polarization was analyzed based on He-Ne graph, where the closer the configuration of graph to He-Ne, the higher the polarization's purity. Extreme polarization purity is required for application in Q-Switched laser cavity. Besides that, the thin film polarizer also has shown greater transmission power than the Glenn-laser polarizer. This might be due to the possibility of the polarizer to have angular tuning, which allows greater transmission. This is a very vital factor to be considered, in order to obtain better laser output energy.

Conclusions

Two types of high energy Nd:YAG laser polarizer have been successfully diagnosed. The selected polarizers comprised of Glenn-laser calcite and the thin film coating on BK7 substrate. Both polarizers produced linear polarization which indicates higher degree of polarization purity. Furthermore after diagnosis, the thin film polarizer had shown slightly higher transmission power compared to the Glenn-laser calcite polarizer. The possibility to tune at various angles allows the thin film polarizer to transmit more power.

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