ENHANCEMENT OF SECOND HARMONIC GENERATION IN DPSS LASER

Nur Ezaan Khamsan, Noriah Bidin, Ganesan Krishnan, Suzairi Daud

Laser Center and Physics Department of Faculty Science, Universiti Teknologi Malaysia, Skudai, Johor, 81310 Malaysia.

nur.ezaan@gmail.com, noriah@utm.my, k.ganesan@utm.my, suzairi@utm.my

1.0 Introduction

High-power diode-pumped compact visible lasers have attracted much attention. A diode-pumped solid-state laser (DPSSL) with high efficiency, high output power, a good spatial beam profile, and good stability is highly desired for use in a lot of applications such as material processing holography, range finding, target illumination and designation, satellite and lunar ranging, thermonuclear fusion, plasma experiments, and in general for scientific work requiring high power densities such as pumping other laser crystals. Laser diode with 808 nm wavelength is the key component in the development of diode pumped solid state laser (DPSSL). Much higher pumping intensity can be achieved using laser diodes instead of flashlamps as pump sources for solid-state lasers because of laser diode high spatial and spectral brightness. The main advantages of diode lasers over flashlamps as pump sources are overall laser efficiency and extended pump-source lifetime. The increase in efficiency is due to improved use of the optical pump radiation. Solid state laser like Nd:YVO_4 has optical absorption only in relatively narrow wavelength bands; thus only small portion of the broadband flashlamp energy passes can be absorbed and the rest just passing through the material without being absorbed. On the other hand, diode laser output is narrowband; thus most of it is absorbed and utilized.

2.0 Methodology

The fundamental of 1064 nm produced from laser diode pumped Nd:YVO_4 laser can be converted into frequency doubler by introducing Potassium Titanyl Phosphate (KTP) crystal. The KTP crystal and output coupler are working in the room temperature The optical alignment for this particular experiment is shown in Figure 2.1. The KTP crystal was properly inserted in the beam path of Nd:YVO_4. After adjusting slightly the position of KTP crystal, a green beam of 532 nm was appeared. Finally, the output coupler of 532 nm was placed at the end of the cavity. The output coupler was slightly adjusted until a contrast of green light is generated. The pumping current of the diode laser was adjusted in the range of 7 – 15 A, and the power of green light was measured.

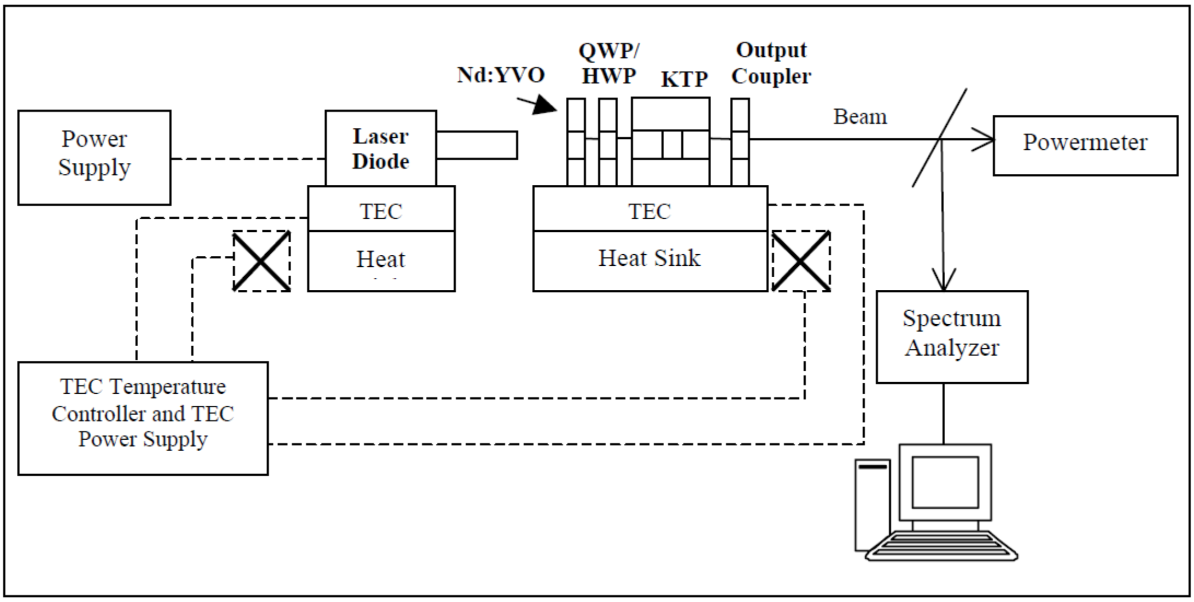


Figure 2.1 Schematic diagram of second harmonic

In order to produce a good quality green beam, further experiment was carried out to optimize the laser output power. The techniques that were used to optimize the laser output power by using phase matching technique and by improving the polarization of the fundamental beam.

For the phase matching technique for the KTP crystal, the KTP was placed on a rotator. The KTP was rotated precisely in the range 1 – 10 degrees with the increment of 1º on each rotation. The power of transmitted beam green laser was measured as a function of rotation angle by powermeter. The experimental set-up for this studied is shown in Figure 2.2.

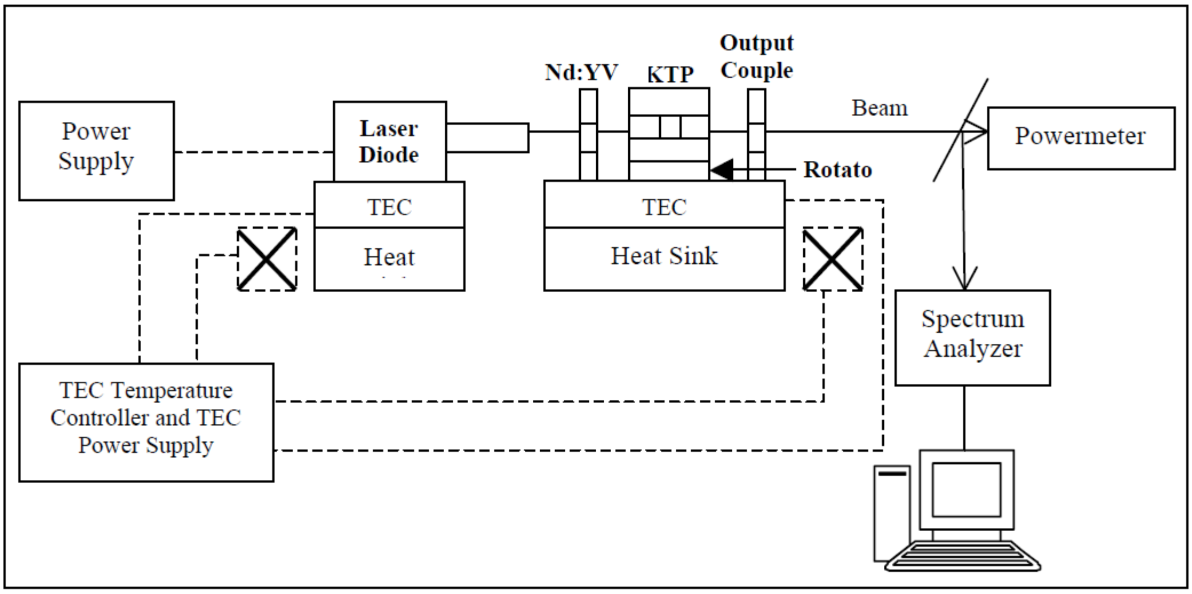


Figure 2.2 Schematic diagram of optimizing the SHG by phase matching technique

There were two types of polarizer involved in this investigation, which were quarter wave plate (λ/4) and half wave plate (λ/2). This is performed to enhance the purity of polarization of the light before entering the KTP crystal. The experiment was carried out in the room temperature. The crystals were interposed in the infrared beam as shown in Figure 2.3. The green light was measured after inserting the crystals. In order to optimize the SHG the crystals were adjusted. Once this position was determined, the maximum intensity of green light was achieved.

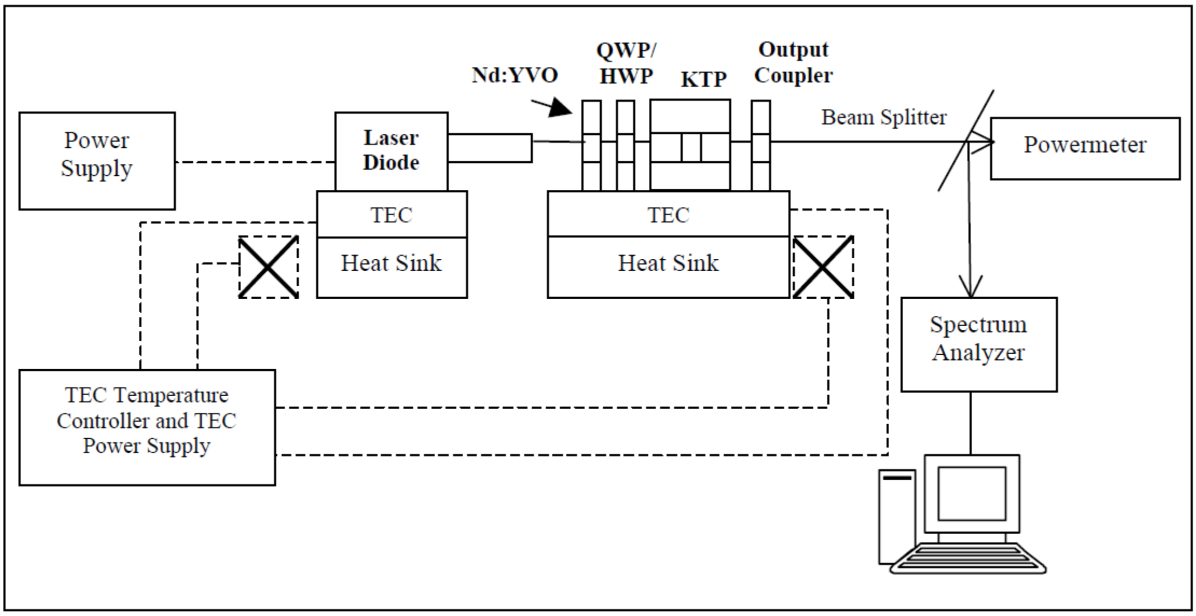


Figure 2.3 Optimization of SHG by λ/4 and λ/2 wave plate

3.0 Second Harmonic Generation (SHG)

Second harmonic generation is an attractive technique for the generation of light in the visible range. Frequency doubling in a nonlinear optical crystal is a common technique for generating coherent radiation in a frequency regime. In SHG experiment, the conversion of a fraction of laser light from its original wavelength of 1064 nm to its second harmonic at a wavelength of 532 nm is studied. This conversion takes place by focusing the laser beam in a nonlinear birefringent crystal of Potassium Titanyl Phosphate (KTP). KTP crystal has been extensively studied for applications on SHG of 1064 nm output of Nd:YVO_4 lasers due to its large quadratic nonlinearity as well as capability of noncritical phase matching.

The phase mismatch between the polarization wave and generated electromagnetic wave is measured in the SHG experiment. The refractive indices are depending on angle, temperature and wavelength. Any changes of these parameters will cause deviation from the exact phase matching condition. To obtain significant amount of power, it is necessary to achieve a condition where the phases of these two waves are matched. This phase matching conditions ensure that the generated second harmonic light interferes constructively in the forward propagating direction. Adjusting the polarization, geometry and angle of the system result in optimization of green laser. In this study, only the dependence of the refractive indices on angels and wavelength were studied as follow.

3.1 Phase Matching Technique

Phase matching technique is one of the most important aspects in efficient second harmonic generation. A study was carried out to investigate the particular phase matching angle for KTP crystal. Angle tuning of the birefringent crystal allows the phase matching conditions to be adjusted by changing the refractive indices. A rotator was employed to perform the phase matching angle experiment. The KTP crystal was rotated in the range between 0º to 5º. The rotation was conducted in two opposite direction, one following the clockwise and the other is counter clockwise. The power of the transmitted beam was measured by powermeter. The results are summarized in Figure 3.1.

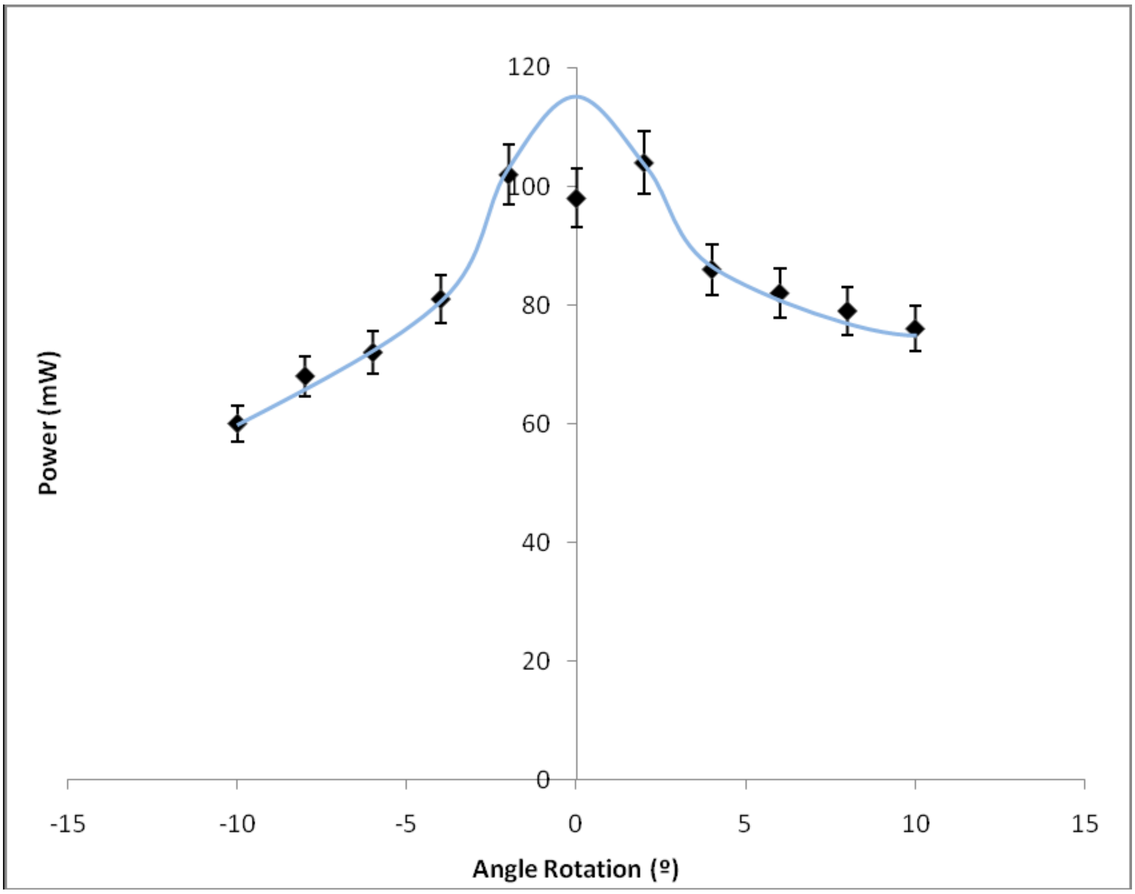


Figure 3.1 Power versus angular rotation of KTP crystal.

Figure 3.1 shows the output power against the rotation angle which varied in the range of -10º to 10º. Generally, the graph is initially increased from -10º to -4º, followed by a constant value from -2º to 2º and decrease when rotational angle greater than 4º. The highest value of output power is recorded at 104 mW and the lowest value is 60 mW. The pattern of the graph can be explained by the polarization state of the beam within the particular region. As can be seen from the graph, the maximum transmission is recorded at the angle of 0°.

This phenomenon occurs due to constructive interference between the second harmonic waves generated by the separate crystal planes. Within these range of angle, the beam are in phase or having the same polarization state. In the other case, at the rotation angle other than -2º to 2º, the beam is said to be out of phase due to the structure of molecule no longer in line with the optical axis. The angle between the separated crystal planes generates certain degree of destructive interference between the waves, and leads to attenuation that cause the decrement of output SHG power. For the rotation angle far greater or lower than this range, the output power from the crystal is very low. No second harmonic will be produced due to diffusion and scattering of light in the crystal. Hence, it is important to rotate the

KTP crystal to find the matching angle between the crystal and polarization of the incoming beam. Otherwise, there is no second harmonic detected or SHG produced with poor quality and low power. Thus, maximum output of second harmonic can be achieved by identifying the phase matching angle of the crystal. In this experiment, the phase matching angle of the KTP crystal is in the range of -2º to 2º since it produced maximum output power for second harmonic.

3.2 The Enhancement of SHG with Quarter Wave Plate and Half Wave Plate

Anistropic materials are defined as materials where the interaction between the atoms constituting the medium is not the same in all direction. Natural anistropic normally occurs in crystalline materials. In anistropic material, a plane polarized waves can only be transmitted in one of two mutually orthogonal directions. KTP is one of the examples of anistropic material. It is a nonlinear optical material characterized by large nonlinear optic coefficient, wide transparency from 350 nm to 4400 nm with moderate damage threshold. Thus, as anistropic materials, extreme polarization purity is required in order for wave to be transmitted through the KTP crystal.

Quarter wave plate (QWP) and half wave plate (HWP) can be use to achieve purity of polarized light. The enhancements of second harmonic waves were studied using Nd:YVO_4 laser as fundamental source. The enhancement of second harmonic was studied using 3 different systems by using a quarter wave plate, half wave plate and without any application of polarizer.

The second harmonic generation was induced via the application of quarter wave plate. Graph in Figure 3.2 show the profile of second harmonic generation with application of quarter wave plate was plotted against Nd:YVO_4 pumped source.

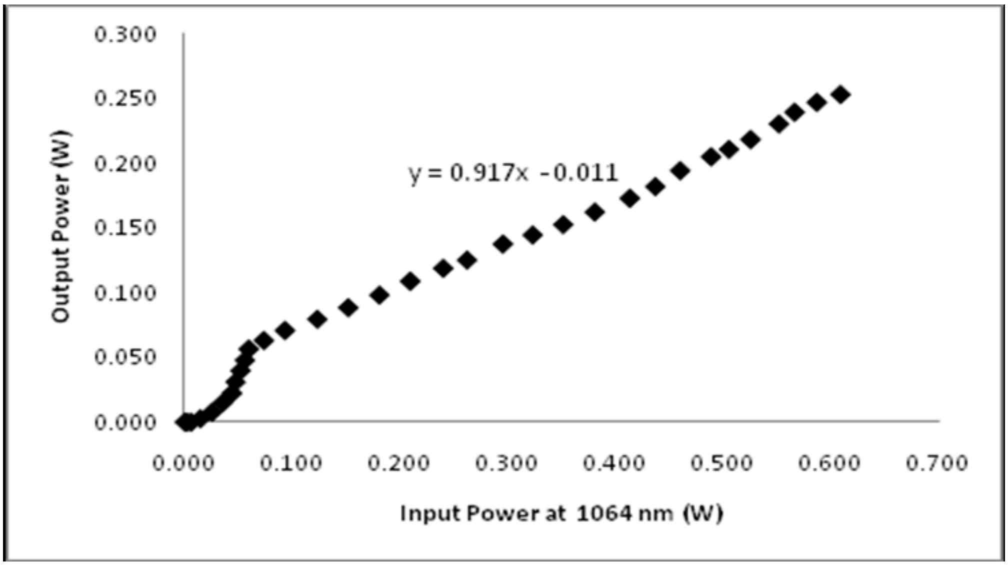


Figure 3.2 Output power versus input power at 1064 nm for quarter wave plate.

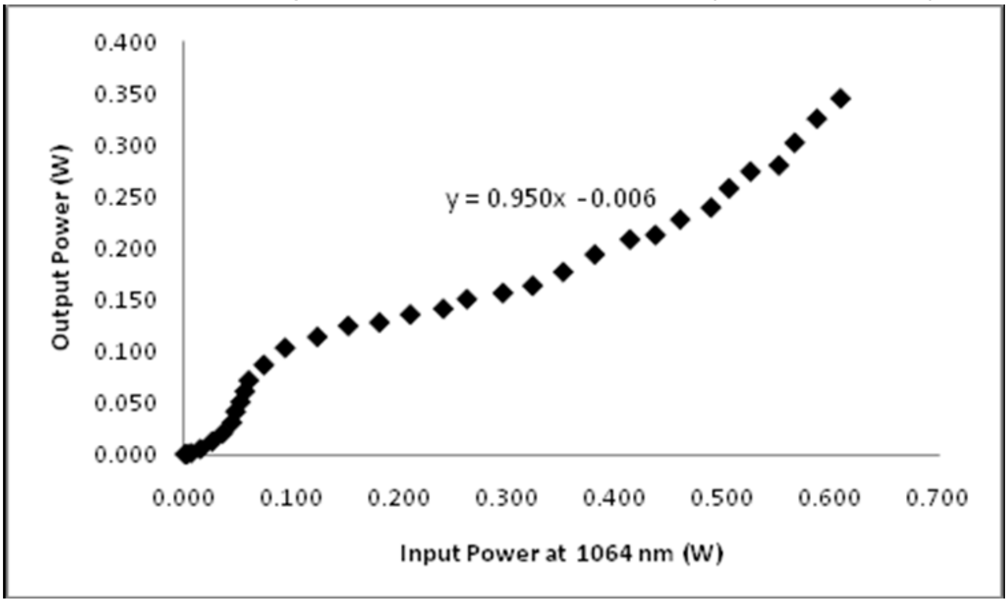
A linear equation obtained from the graph. From the equation, y = 0.917x + 0.011 the slope efficiency found at 91.7 %. The present of quarter wave plate was found increasing the generation of second harmonic generation. The threshold power for second harmonic generation with application of quarter wave plate was 0.012 W.

A graph of output power of second harmonic generation with application of half wave plate was plotted against the input power of Nd:YVO_4 as pumped source such as shown in Figure 3.3.

Figure 3.3 Output power versus input power at 1064 nm for half wave plate.

The linear portion of Figure 3.3 has a relationship as y = 0.950x + 0.006. The conversion efficiency is 95.0 % with threshold power of 6.3 mW. This indicates that the half wave plate can be used to polarize the fundamental beam of 1064 nm and capable to produce frequency doubling phenomenon.

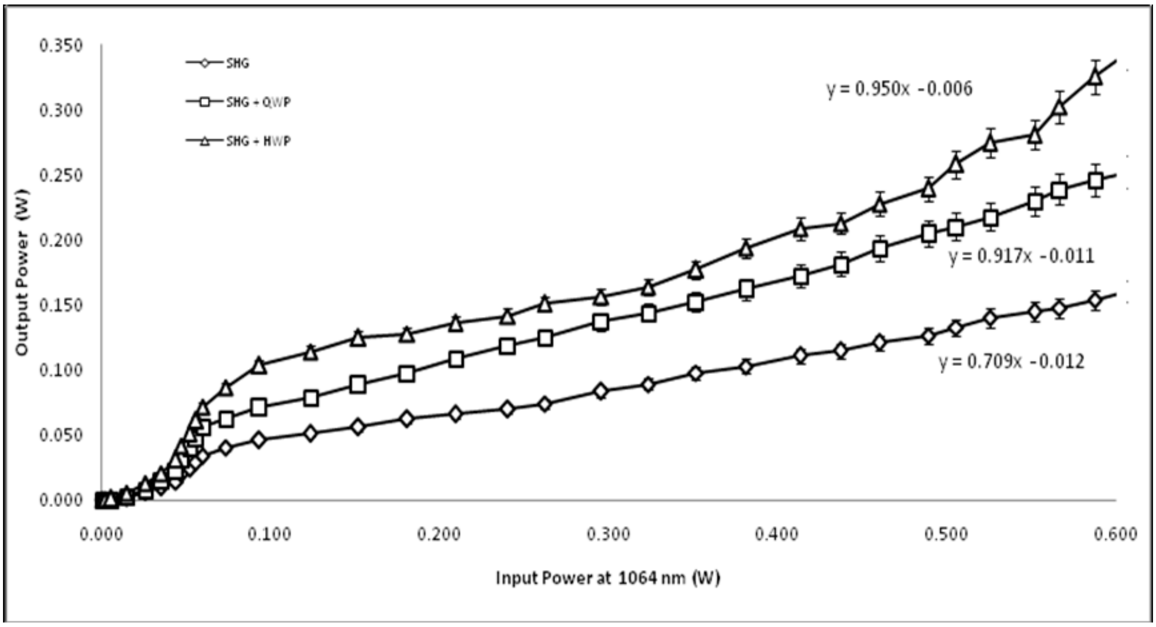
The comparison results of second harmonic generation from various application of polarizer are shown in Figure 3.4. The combined results show the second harmonic waves generated from 3 different systems. The systems were



designed with the usage of quarter wave plate, half wave plate and without any wave plate respectively.

Figure 3.4 Comparison of output power versus input power for different systems.

Figure 3.4 show the comparison of second harmonic generation beam modulated via both polarizers and without polizer. The application of polarizer enhanced the intensity of SHG beam. The top line represents the results obtained via the application of half wave plate. The absence of polarizer shows that the optical to optical conversion is almost ~71 % with threshold ~17 mW. With the application of quarter wave plate, the efficiency is ~ 92 % with less threshold power of 12 mW. Further enhancement was observed by the application of half wave plate, whereby



the efficiency can be achieved up to 95 % with less threshold power of ~ 6 mW.

According to the comparison result, half wave plate produced results with higher efficiency compared to quarter wave plate. In general, polarizer provides purity in polarization state or direction of vibration of the light. The role of quarter wave plate was to change the waveform from circular to linear or vice versa. But for the light interaction with nonlinear beam like KTP, linear polarization was required. So, the quarter wave plate in this particular case purposely used to convert the circular into linear polarization.

Higher efficiency obtained from half wave plate due to the change in polarization state. The changes from vertical to horizontal state of linear polarization will results in excellent phase matching between the ordinary and extraordinary rays, hence increased the efficiency. Since the enhancement of half wave plate was found much higher compared to quarter waveplates, this confirmed that the conversion was more preferable to match with the mode of SHG. As a result, half wave plate is a better selection to enhance radiation second harmonic generation.

4.0 Conclusion

A nonlinear crystal of potassium titanyl phosphate (KTP) was employed as a frequency doubler. The fundamental of solid state laser radiation was converted from invisible of infrared light with wavelength of 1064 nm to visible green light 532 nm. The green light has threshold power of 0.0169 W with slope efficiency of 70.9 %.

The second harmonic beam later was enhanced using two types of polarizer which is quarter wave plate and half wave plate. The conversion efficiency was found increase. The quarter wave plate capable to convert almost 91.7 % with threshold power of 0.012 W. Further enhancement of second harmonic generation was done using half wave plate. The SHG beam was realized higher than the other two conditions. Half wave plate can convert the SHG almost 95.0 % with threshold power of 0.0063 W.

Enhancement second harmonic generation can be performed since the fundamental beam was ensured to have better purity. This is important characteristic to match with generation of second harmonic beam in the nonlinear crystal. As a result of good mode matching between the pumped and second harmonic generation beam, the transmitted intensity from KTP become much higher.