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DIAGNOSTIC THERMOELECTRIC COOLER PERFORMANCE IN DIODE PUMPED SOLID STATE LASER

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Abstract. Thermoelectric cooler (TEC) system is important in order to stabilize the output of Diode Pumped Solid State Laser (DPSS) laser. The aim of this study is to diagnose the performance of TEC in DPSS system. High power diode laser (DL) driver was utilized as a pumping source. The current of the driver was verified and the temperature of the DL and KTP were measured. The threshold current for DPSS laser was obtained at 7 A. The temperature of diode laser was found drastically increase before threshold current. Beyond that point the temperature remained constant at 25.4°C. However in KTP crystal, three phases produced before achieving the same constant temperature of DL. Thus TEC was effectively controlled the temperature of KTP at ambient temperature of 25.4°C after diode laser was pumped with current greater than 18 A.

Keywords: Thermoelectric cooler; DPSS Laser; diode laser; KTP crystal; temperature

Abstrak. Sistem penyejukan termoelektrik (TEC) amat penting untuk menstabilkan keluaran DPSS laser. Tujuan kajian ini adalah untuk mengenal pasti prestasi TEC bagi sistem DPSS laser. Laser diod (LD) berkuasa tinggi digunakan sebagai sumber pengepaman. Arus pengepaman diubah dan suhu bagi LD dan KTP dirakamkan. Arus ambang untuk DPSS laser beroperasi adalah 7 A. Suhu bagi LD didapati bertambah dengan cepat sebelum arus ambang dicapai. Kemudiannya berada dalam keadaan stabil pada suhu 25.4°C. Berbeza dengan hablur KTP yang mengalami tiga fasa sebelum mencapai suhu stabil. TEC berjaya mengawal suhu KTP laser pada suhu bilik iaitu 25.4°C selepas dipam dengan arus pengepaman yang lebih besar dari 18 A.

Kata kunci: Penyelukan termoelektrik; DPSS Laser; laser diod; hablur KTP; suhu

1.0 INTRODUCTION

In recent years, the electronic industry has developed rapidly and the miniaturization of electronic components has been ongoing. As components have shrunk, the chip-level power density has continued to rise greatly. Therefore, thermal management is becoming a critical issue in system performance. Moreover, the electrical stability of many pieces of electronic equipment, such as diode laser, semiconductor optical devices, infrared detectors, and others, should be improved, to ensure electrical stability and rapid electrical–optical transmission. Traditional thermal management devices,

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such as a fan and heat sink, no longer appropriate in such electronic equipment. Thermoelectric Cooler (TEC) is therefore employed to control the thermal and electrical stabilities [1, 2]. Thermoelectric cooler (TEC) is a cooling system. It is normally used for a Diode Pumped Solid State (DPSS) laser. It is used to control and stabilize the temperature of pumping source of diode laser (DL), frequency doubled of Pottasium Titanyl Phosphate (KTP) crystal and other solid state laser components [3,4].

TEC has been practical for specialized application since the late 1960s. Recent reports of material improvement through novel processing techniques may make TEC practical for more everyday application [5]. TEC is usually used for thermal management in smaller units where precise temperature stability is critical. This cooler not only provide a way to remove excess heat efficiently, but are also solid state devices that can be incorporated in feedback control loops [6].

In general every device which current applies to it produces heat. Most of the time raise of temperature causes some problems which affect the function of the device. Lasers are devices which require current to produce some Watt or miliWatt of light. In the DPSS laser system, thermal management of the pumped laser is very important, it is critically affects laser wavelength, output power, threshold current, slope efficiency and operating lifetime [7].

The output of DPSS laser must be maintained constantly. Temperature affects the wavelength of a diode laser due to the change in physical dimension of the internal cavity. Variations in temperature also affect pumping efficiency. Diode current also affect wavelength, partially due to the temperature. So, as a diode ages and requires more current for the same output, its wavelength will also change. This will have an impact on laser expected lifetime. As temperature varies, shift between modes becomes an issue.

By using cooling elements, temperature is roughly regulated. Therefore by controlling the temperature of the diode laser we can improve the system stability. Cooling a diode laser will have obvious physical effects like shortening of the cavity so mode hopping would be expected.

Each diode laser may be independently temperature controlled to tune its emission wavelength to match the absorption wavelength of the solid state laser material being pumped. For optimal performance and long life, the pumped diode, YAG or vanadate, and KTP must all have their temperature regulated. Both temperature of the Nd:YAG and the KTP crystals must be maintained in order to avoid thermal damage of the crystals.

Hence, the aim of this project was to study the performance of the TEC in DPSS system. The testing part involved pumping source, active medium and second harmonic generator.

2.0 THEORY

Thermoelectrics are based on the Peltier Effect, discovered by French watchmaker Peltier in 1834 [8]. Peltier discovered that when an electric current cross the junction between two dissimilar conductors, heat is absorbed or liberated at the junction as illustrated in Figure 1. If the direction of current flow is reversed, the effect also reverses [9]. It is also described as a solid state method of heat transfer generated primarily through the use of dissimilar semiconductor material (P-type and N-type) like conventional laws of thermodynamics [10]. The Peltier Effect is one of the three important thermoelectric effects, the other two are known as the Seebeck Effect and Thomson Effect. These last two effects normally act on a single conductor. Whereas the Peltier Effect is a typical junction phenomenon. However these three effects are related to each other by a simple relationship.

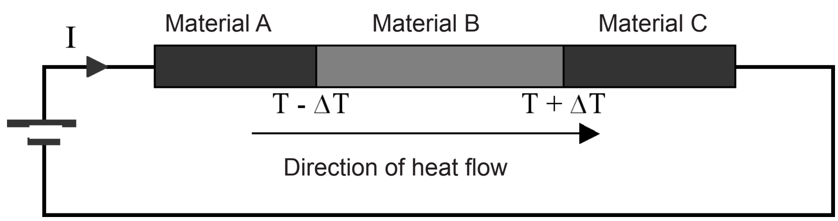

Figure 1 Peltier effect on the junction between dissimilar conductors

In principal when electron move from the P type material to the N type material, in other word as electron jump to higher energy level, they will absorbed thermal energy (heat). On the other hand, if electron jump to a lower energy state, the reverse occur and electron going to release heat. Basically this phenomenon can be illustrated in two level energy such as shown in Figure 2.

Thus, if these two phenomena are combined by the meant of electrical connector, both function of absorbing and releasing heat will joint together to form cooling system. This is the basic concept apply in thermoelectric cooler. In a typical thermoelectric module, two thin ceramic wafers with a series of P and N doped bismuth-telluride semiconductor materials were sandwiched between them. The ceramic material on both sides of the thermoelectric adds rigidity and the necessary electrical insulation.

The N type material has an excess of electrons, while the P type material has a deficit of electrons. One P and one N make up a couple, such as shown in Figure 3. The thermoelectric couples are electrically in series and thermally in parallel. A thermoelectric module can contain one to several hundred couples.

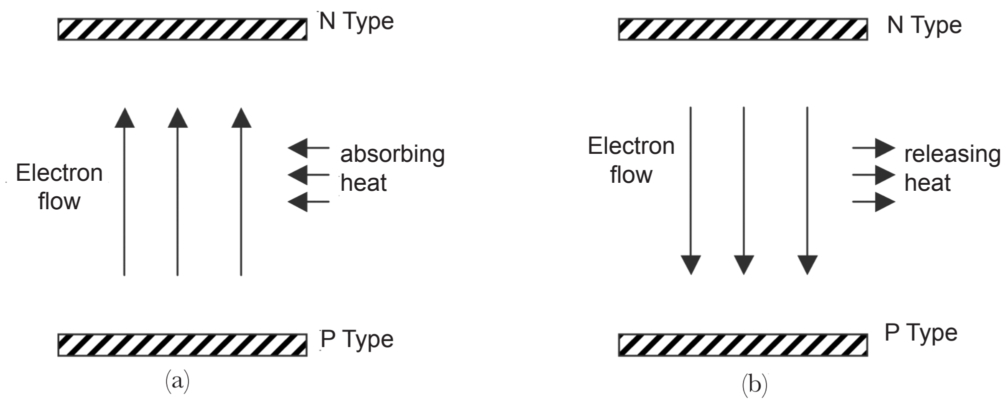

Figure 2 The effect of electron jump in two level energies (a) electron flow from lower to high level requires absorbing heat (b) electron flow from higher to the lower level which cause releasing heat

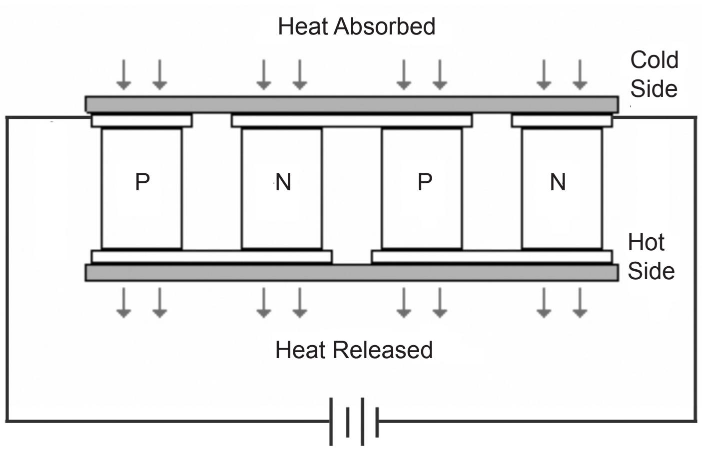

Figure 3 The principle of thermoelectric module

The thermoelectric can be alternately absorbing and releasing energy, depending on the direction of the current. In application requiring both heating and cooling, the design should focus on the cooling mode. Using a thermoelectric in the heating mode is very efficient because all the internal heating (Joulian heat) and the load from the cold side is pumped to the hot side. This reduces the power needed to achieve the desired heating.

3.0 METHODOLOGY

A DPSS model LYDPG-1 was employed as a source of laser light DPSS laser comprised high power diode laser which is used as an optical pumping source. The wavelength of the diode laser is 808 nm. This diode laser using forward current as a pumping energy. The heat liberated during pumping process was controlled by TEC 1.

Diode laser was used to optically pump active medium which is consist of a disc Nd:YAG crystal. The laser crystal emitted IR beam of 1064 nm wavelength. A KTP crystal was employed as a second harmonic generator which responsible to convert the original beam into half wavelength. As a result, the output of DPSS laser then producing visible light of 532 nm. In order to maintain the output remain constant, both crystals (Nd:YAG and KTP) are placed on the TEC 2.

Particularly in DPSS laser the thermal energy (heat) from diode laser as well as in KTP crystal are absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. Meanwhile, power supply from TEC provides energy for electrons to move from higher energy level in N type to lower energy level in P type. The DPSS laser also provided controller fan cooling to extract the wasted heat out of the system. Temperature and DL current are displayed in DPSS driver. In this experiment the temperature of DL and KTP were measured by varying the DL pumping current. The schematic diagram of the whole experimental setup is shown in Figure 4.

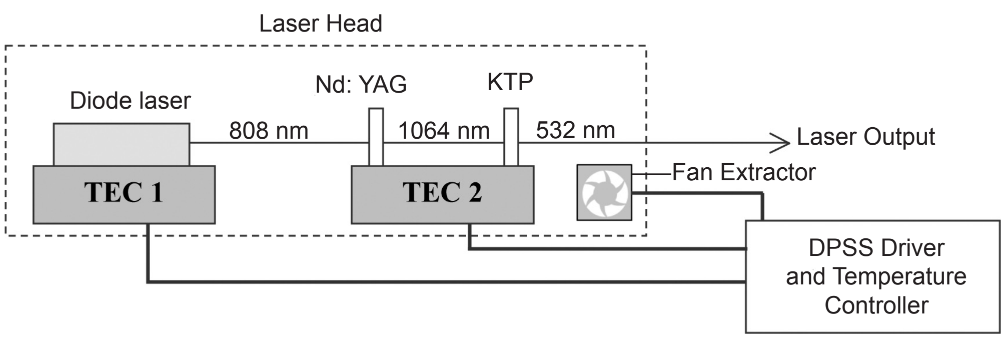

Figure 4 Schematic diagram of the whole experimental setup

4.0 RESULT AND DISCUSSION

The performance of thermoelectric cooler for diode pumped solid state laser was studied by measuring the diode laser (DL) and KTP temperature with the variation of the DL pumping current with the increment of 1 A. The experiment was carried out four times and the average temperature was calculated. The data measurement are used to plot a graph as depicted in Figure 5.

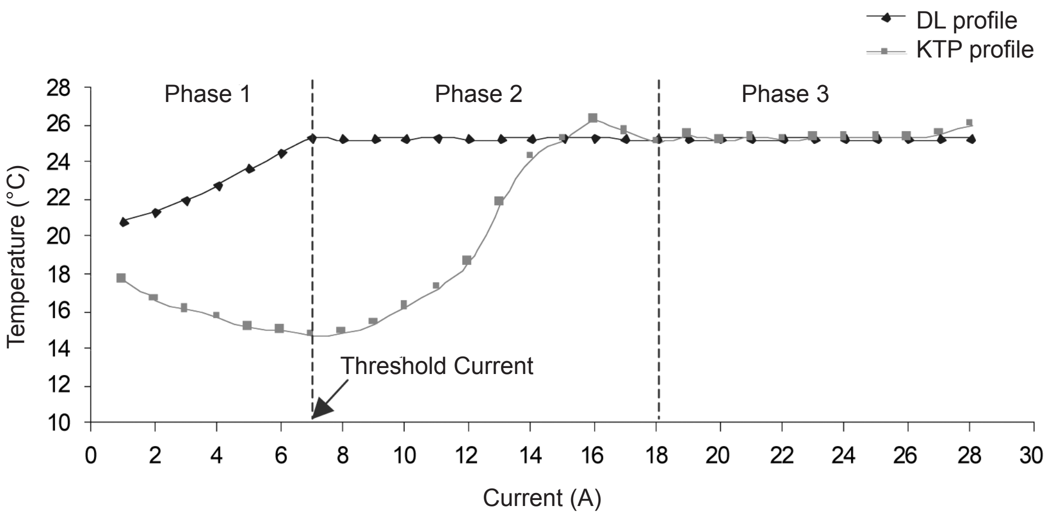

Figure 5 DL and KTP temperatures as a function of current

Two curves are shown in Figure 5, owing to the DL and KTP profile respectively. Initially the temperature of DL curves was increased drastically with the DL current. Every device will produce heat when applied by current. Hence, the increasing of forward DL current produce proportional effect to the temperature of DL. The threshold current for the diode laser was found to be at 7 A. Beyond this point the DL temperature remained constant at 25.4°C. This indicates that TEC has controlled the temperature of DL similar to the ambient temperature, immediately after lasing.

According to the KTP temperature profile, the configuration of the curve shows three phases. In the first phase the temperature gradually decreased down to a minimum temperature of 14.8°C corresponding to the threshold current of 7 A. This is because the diode laser still not have sufficient energy to optically pumped the Nd:YAG crystal. Consequently no infrared beam of 1064 nm was emitted. As a result, KTP crystal has not been exposed by infrared beam. In addition, the DPSS laser system is also provided with external cooling using a fan. Before Nd:YAG crystal was lased, the thermal energies carried by diode laser beam which exposed to the optical components were extracted by the fan. In this particular stage the cooling fan dominates the heat liberated from the laser system. As a result the temperature of KTP crystal was lower than ambient temperature.

In the second stage of the KTP profile of Figure 5, the temperature gradually increased with respect to the pumping current. Physically the occurrence of gradual increase of temperature was cause by fan extractor. Meanwhile, the raised of the temperature was subjected to the thermal energy illuminated by infrared (IR) beam from Nd:YAG crystal. The nonlinear KTP crystal absorbed the IR beam and emitted of green light. Since the smaller size of KTP crystal, some of the exposed beams were liberated as a wasted heat, which also contributed to raise the temperature.

In the third stage, temperature of the KTP crystal in Figure 5 is almost constant. This occurs after the diode laser have been pumped by 18 A forward current. This indicates that, the TEC 2 started controlling and stabilizing the temperature of KTP after the pumping current is greater than 18 A. The TEC 2 also controls the KTP temperature similar to the ambient temperature of 24.5°C. Relatively KTP crystal required higher energy to initiate the TEC 2. This is because KTP is not directly heated by current as compared to the diode laser.

However, the temperature of the KTP crystal was fluctuating at the high end of pumping current starting at 26 A. This is possibly because of the heat produced by high power infrared beam. In addition the raise of temperature might be contributed from wasted heat liberated either by radiation, convection and conduction from the laser system.

As a summary, TEC immediately controlling the temperature of diode laser after threshold current of 7 A. In contrast, the temperature of KTP can only be stabilized after the pumping current exeed more than 18 A. Large current needed to stabilize the KTP is due to the joint cooling from TEC and fan extractor.

5.0 CONCLUSION

The performance of the TEC in DPSS system was successfully studied. TEC was applied on the optical pumped source that is diode laser and optical components including active medium of Nd:YAG crystal and second harmonic generation of KTP crystal. Fan extractor also used as external cooling in DPSS system. The result of investigation shows that the TEC was managed to control the temperature at 25.4°C. It was operating faster in Laser Diode compared to KTP crystal. This is because current was directly applied to the diode laser whereas KTP was only heated after Nd:YAG was lasing. In addition, the existing of fan cooling may reduce heating process. The system need pumping current of 18 A for the TEC to totally control and stabilize the temperature of DPSS laser.

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