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Surface Temperature Measurements Of Diamond

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ABSTRACT

Diamond has the highest thermal conductivity among known materials, and as such finds uses as an industrial tool in areas where dissipation of excess heat is a requirement. In this investigation we set up a laser system to heat a diamond sample by linear absorption of the laser radiation by the sample. To heat a diamond to high temperature, the laser system should have sufficiently good power stability, beam position and suitable wavelength for absorption The temperature is then measured during the heating process by measuring the thermal radiation spectrum of the sample and using the Planck radiation function. Such a system is the first step in an ultimate aim of determining the temperature induced defects in industrial diamond.

INTRODUCTION

Diamond is the hardest known natural substance and is composed of pure, crystallised carbon. There are many type of diamond such as Industrial diamond, Commercial diamond and Synthetic diamond. Commercial diamond is a transparent piece of diamond that has been cut and polished used for example in jewellery. Synthetic diamond is diamond produced through chemical or physical processes in a laboratory. An example is chemical vapour deposition. Industrial diamond is used for industrial application such as drilling or cutting[1-2].

Industrial diamond is used as the mechanical tips of drilling bits because of its high thermal conductivity, and its material hardness. However, the diamond nevertheless reaches very high temperatures during a typical drilling experiment due to friction, and it is believed that the high temperature lead to stress induced damage through dislocations of the lattice[1-2].

In this study, we wish to heat an industrial diamond sample by means of optical absorption of laser beam, and the measure the resulting temperature profile on the surface of the diamond optically by means of emission spectroscopy, pyrometer and thermocouple. Finally, with the heating and temperature known and repeatable, we wish to study temperature driven defects in the diamond.

OPTICS AND LASER

The PL6 CO_2 laser was the heating source chosen for attaining high temperature in an industrial diamond. The PL6 CO_2 laser operates in the middle infrared region. It is a continuous wave laser has a peak power ~50 W at wavelength of 10.6 µm. It can however be tuned to produce laser light in the range of 9 µm to 11 µm.

The CO_2 laser was aligned by using HeNe laser, in the near-field and far-field respectively to the beam combine and flat mirror. By varying the grating position of the laser, the power and wavelength were recorded for each grating positions. The power meter was used to measure the power and the spectral analyser was used to measure the wavelength. The graph of power versus wavelength was plotted.

For a slit distance of x mm from the focused mirror the beam was scanned across by varying the cross sectional slit position relative to the beam. Readings of beam power were recorded for each step. This was repeated for different values of slit position. The origin software was used to plot the slit position versus power to get spot size (w) of the beam. Then a plot of slit distance versus the spot size (w) was made. A polynomial fit gave the equation of the plot. Solving the beam propagation equation which given in equation 1 gives beam factor (M^2), waist (w_0) and the waist position (z_0)[3].

$$w^2(z) = \left(\frac{M^2\lambda}{\pi\omega_0}\right)^2 z^2 - 2z_0\left(\frac{M^2\lambda}{\pi\omega_0}\right)^2 z + \left(\frac{M^2\lambda}{\pi\omega_0}\right)^2 z_0^2 + \omega_0^2 \quad (1)$$

TEMPERATURE MEASUREMENTS

There are many methods to measure the temperature of a body. Here we used a thermocouple and a pyrometer, while future plans involve emission spectroscopy.

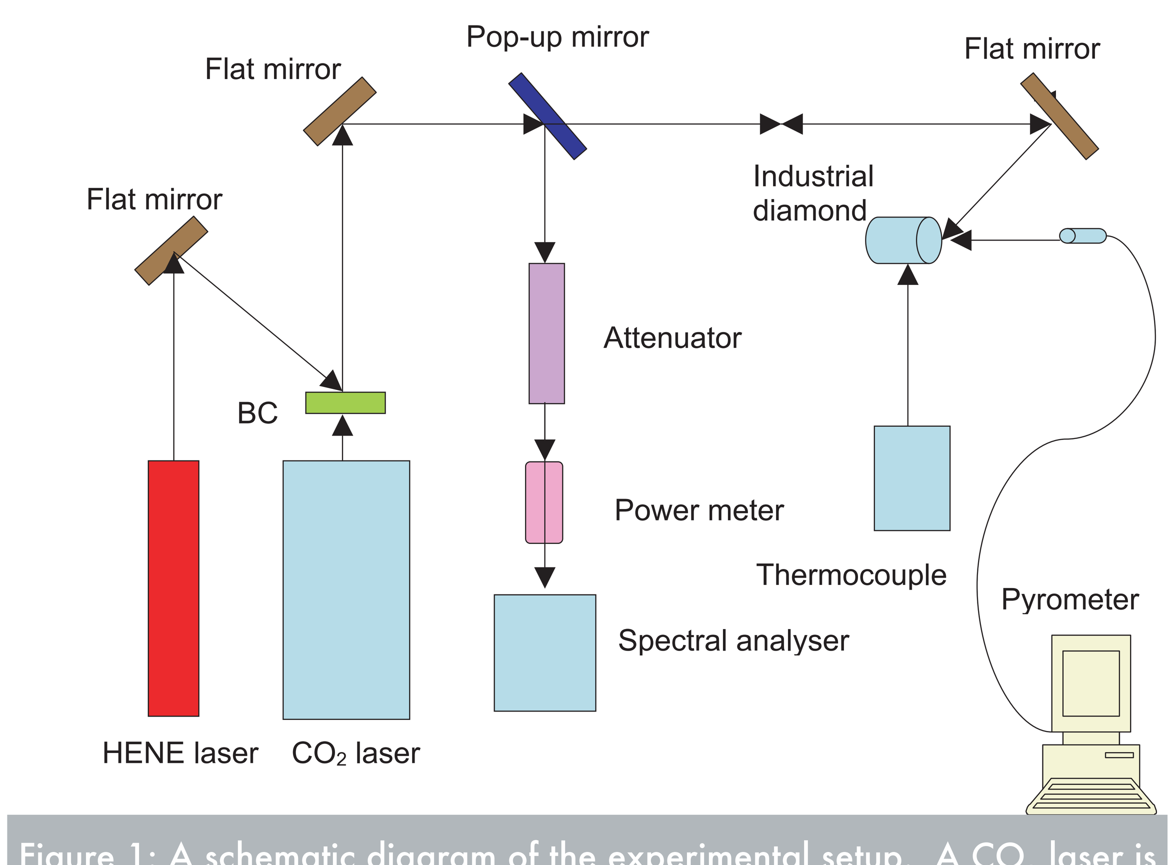

Figure 1: A schematic diagram of the experimental setup. A CO_2 laser is used to heat the sample, with the resulting temperature measured using a pyrometer and thermocouple

A thermocouple is a temperature sensor that consists of two wires connected together made from different metals, which produces an electrical voltage that is dependant on temperature. A Newport electronic thermocouple was used to measured temperature. It can measure the temperature range from 22°C to 1200°C. The temperature measurement was measured during the heating process by attaching the thermocouple to the industrial diamond. The experimental set up shown in figure 1.

Our future plans include emission spectroscopy, which uses the range of electromagnetic spectra in which a substance radiates. The substance first absorbs energy and then radiates this energy as light. The concept of doing this is to employ the Planck radiation law, and from the derived emission spectrum of the body, find the associated temperature.

$$I(\lambda) = \frac{c_1\varepsilon(\lambda)}{\lambda^5\left(\exp\left(\frac{c_2}{\lambda T}\right) - 1\right)} \quad (2)$$

Here c_1 and c_2 are constants[4-8]. An example of such an optical system is shown in figure 2.

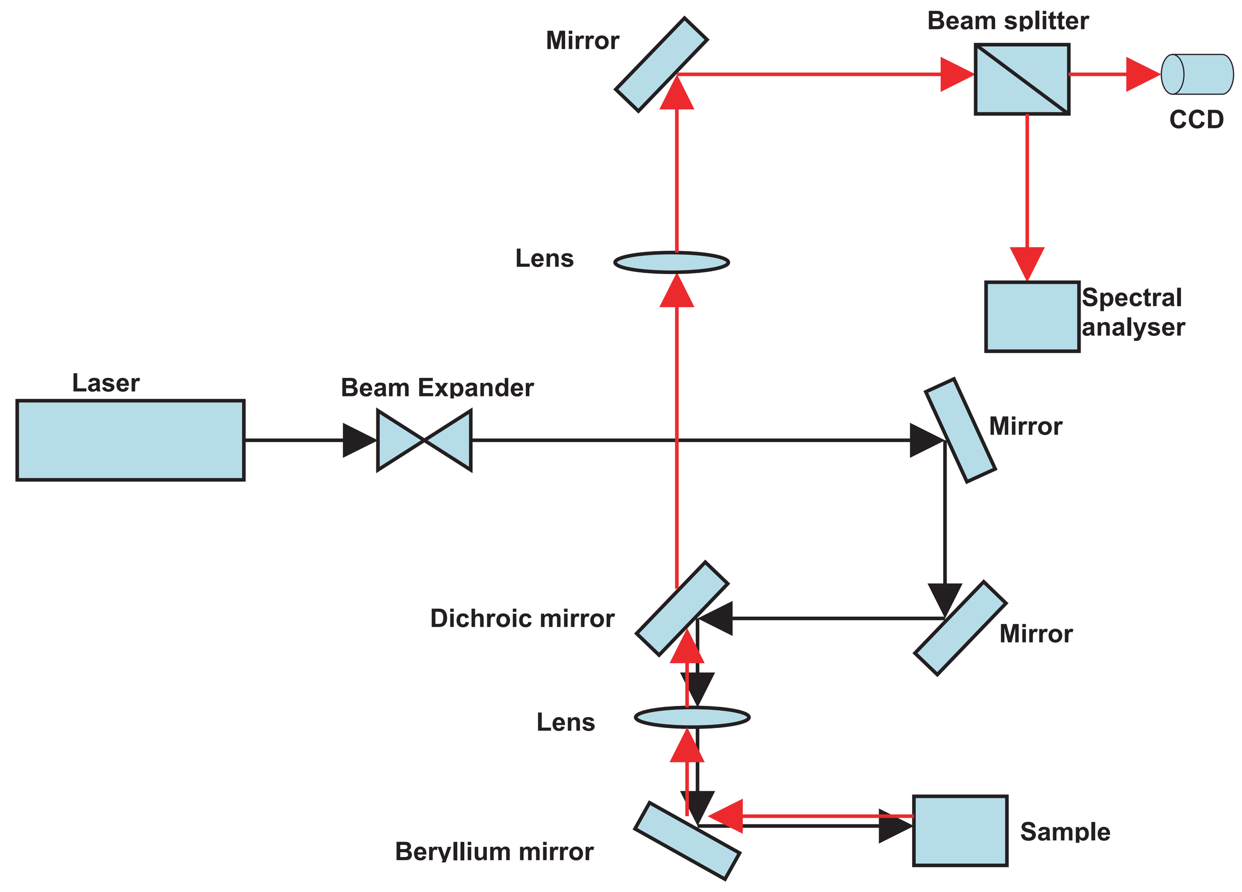

Figure 2: A schematic of a setup for laser heating with temperature measurement by emission spectroscopy

RESULT AND DISCUSSION

The power spectrum of CO_2 laser graph is given in figure 3 and was plotted from the wavelength range of 9 µm to 11 µm. The waist (ω_0 = 1.215 mm) of the beam and beam factor (M^2 = 1.68) were calculated by solving a beam propagation equation from the polynomial fit. This result was used for choosing the correct optics and the correct wavelength of the laser heating system for temperature measurements.

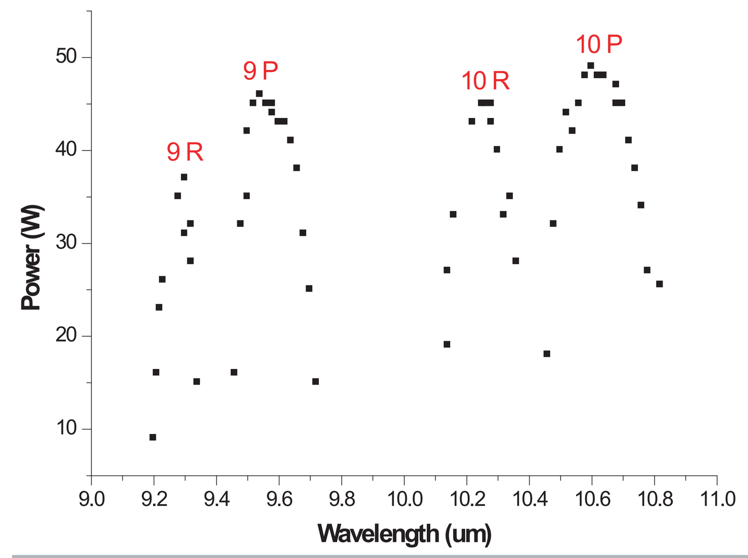

Figure 3: Power spectrum of the CO_2 laser showing the power extraction across the various rotational and vibrational bands in the 9 – 11 µm range

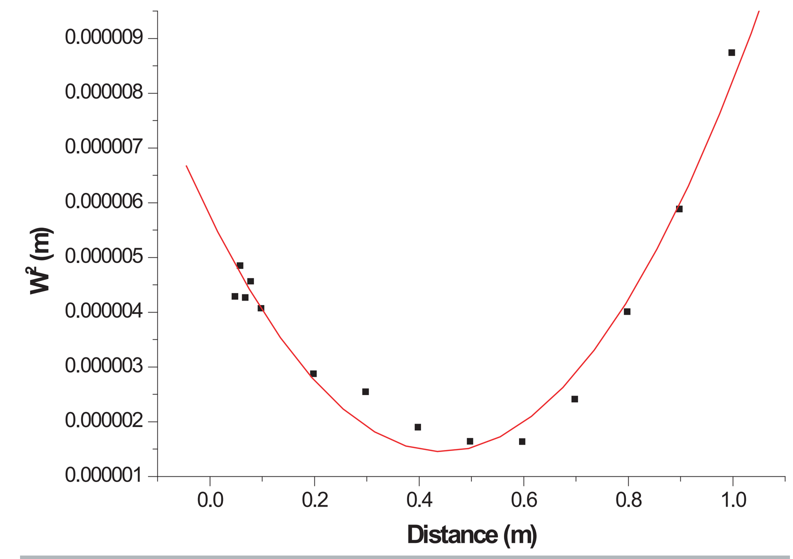

Figure 4: Measurements of the laser beam size as it propagates enables one to determine the beam quality factor, M^2. This is needed for predicting the beam size throughout the experiment

CONCLUSION

We managed to demonstrate a laser heating process and made temperature measurements of industrial diamond for a heating and cooling session.

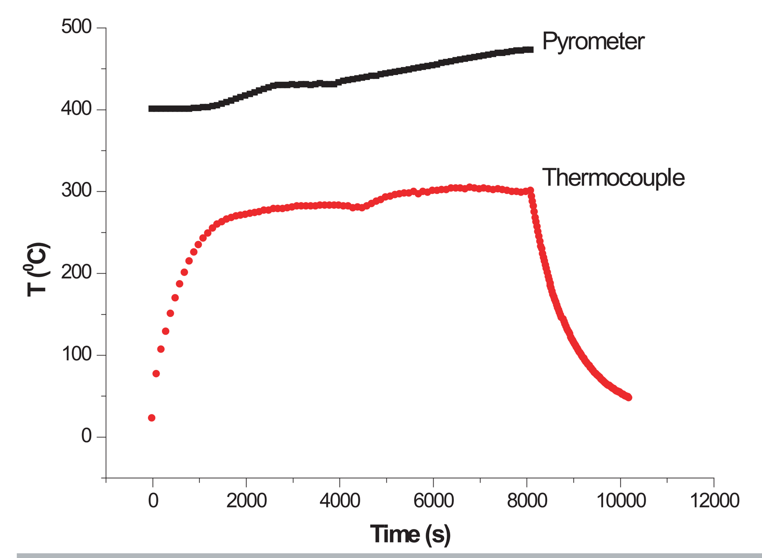

Figure 5: Heating and cooling session of the industrial diamond with the Newport electronic thermocouple, and a heating session with the pyrometer. The pyrometer only measures temperatures above 400°C

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