МЕТОДЫ ИЗМЕРЕНИЙ, КОНТРОЛЯ, ДИАГНОСТИКИ

SIMPLIFIED METHOD OF CALORIMETRIC MEASUREMENTS OF BACKGROUND LOSS IN CRYSTALS

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We report on the measurements of absorption coefficient of the synthetic diamond crystal using an adapted form of laser calorimetry technique at wavelengths of 1064, 640, 532, 452 and 364 nm. The absorption coefficient was found to increase exponentially from 0,03 cm^{-1} at 1064 nm to 0,7 cm^{-1} at 364 nm. (E-mail: vasili.savitski@strath.ac.uk)

Key words: calorimetric method, optical absorption, synthetic diamond.

Introduction

An important consideration for laser intracavity use of single crystal (SC) chemical vapour deposition (CVD) grown diamond [1, 2] is the insertion loss of a material. For diamond, this is typically dominated by absorption associated with nitrogen impurities – predominantly single substitutional nitrogen [3]. The absorption of early generations of SC CVD grown diamond was measured by Turri et al. using laser calorimetry [4]. The absorption coefficients at 1064 nm ranged from 0,003 to 0,07 cm^{-1}. However, much of the materials investigated in this study – including the samples with the lowest absorption – had significant spatially varying birefringence. As van Loon et al. demonstrated [5], this birefringence made intracavity use of such materials problematic. In 2010, Lubeigt et al. reported on the use of low-birefringence material ($\Delta n < 5 \cdot 10^{-7}$) to demonstrate the first continuous-wave diamond Raman laser [2]. However this material had an absorption coefficient of ~0,03cm^{-1} at 1064 nm (inferred from Caird analysis of the intracavity losses [6]). This elevated loss limited the performance of the Raman laser. Subsequently, Friel et al. reported on the growth of single-crystal diamond that combined low birefringence ($\Delta n < 10^{-6}$) with an absorption coefficient at 1064

nm measured to be ~0,001 cm^{-1} by ISO-standard laser calorimetry [3]. Material of this grade was then used to demonstrate an eight fold improvement in the output power of continuous wave diamond Raman lasers [7]. This indicates the importance of understanding the absorption characteristics of diamond if the performance of intracavity Raman lasers is to be optimised.

Experimental results

The single-crystal CVD-grown diamond under investigation was supplied by Element Six Ltd. The same sample was used as in a previous study [1]. It was cut for light propagation along a <110> axis and had a length of 6,5 mm. The crystal had a low birefringence of Δn ~1,3·10^{-6} [1]. The sample had no anti-reflection coatings.

The absorption coefficient of the sample was measured using an adapted form of laser calorimetry. The voltage drop across a Peltier element due to the heat deposited by laser illumination was measured. The measurement set-up is presented in Figure 1a.

The sample under study (1) was placed on a 5,8×3,8 mm Peltier element (2). This, in turn, was attached to a brass heat sink (3) using silver-loaded paint. Thermal grease was used to ensure a proper

thermal contact between the sample and the Peltier element. A CW laser beam at wavelengths of 1064, 640, 532, 452 and 364 nm was incident on the sample under test. Types of the lasers, as well as powers and intensities of laser emission are presented in Table. The laser beam (4) was focused into the sample by a lens (5). After passing through the sample, the beam was dissipated by a beam dump (6). The sample, Peltier element and the brass mount were covered with a styrofoam box (7) to ensure thermal isolation of the set-up. (N.B. In this configuration, it is not possible to distinguish between light absorbed directly in the sample and any small fraction scattered by the sample and subsequently absorbed in the Peltier element. Thus, a higher value of the absorption coefficient is to be expected from this simplified technique compared to ISO-standard calorimetry.)

Table

Characteristics of the lasers used in experiment

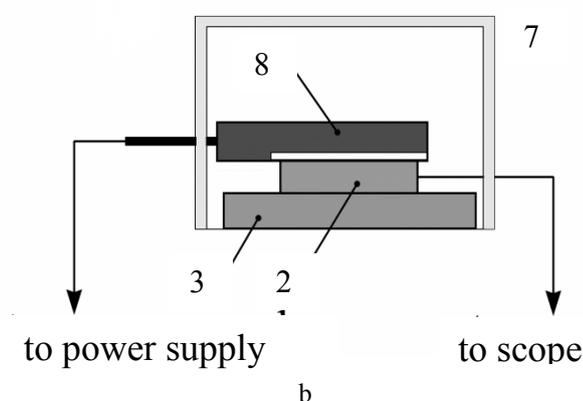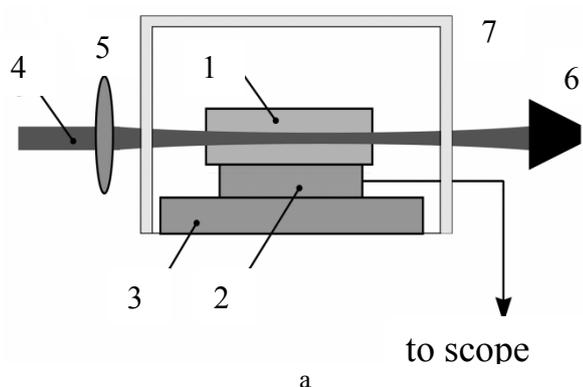| Laser wavelength, nm	Type of the laser	Max power, W	Max intensity in the sample, W/cm^2
1064	Nd^{3+}:YLF	3	380
640	Fiber-coupled laser diode	3	380
532	Frequency-doubled Nd^{3+}:YAG laser	3,6	450
452	Laser diode	0,9	115
364	Ar$^+$ laser	0,49	62

Figure 1 – Schematic diagram of the set-up used for the calorimetric measurements of loss (a), and for calibration of the set-up (b)

In order to calibrate the voltage drop across the Peltier element (Figure 1b), the sample was replaced with a resistor (8) (10 Ω thick-film power resistor (MP915) with the heat dissipated through a 5×6,2 mm surface). The voltage drop across the Peltier element as function of the electrical power supplied to the resistor was measured giving a calibration coefficient C = 5,6 μW/μV assuming that all the electrical power was dissipated as heat in the resistor. The absorption coefficient α of the sample was then calculated using the equation:

$$\alpha = - \frac{1 - \ln\left(\frac{C \Delta U}{P}\right)}{L},$$ (1)

where L is the length of the sample; ΔU is the voltage drop across the Peltier element and P is the laser power entering the sample under test.

The results of measurements of the absorption coefficient of SC CVD diamond crystal are presented in Figure 2 as a function of pump photon energy (solid squares); the solid line is the best fit to the data using an exponential growth function. The absorption coefficient was found to increase substantially from 0,03 cm^{-1} at 1064 nm to 0,7 cm^{-1}

at 364 nm. For comparative purposes, calorimetric absorption measurements were made on a 5 mm long undoped 3 × 3 mm YAG sample (Molecular technology, MT-Berlin). The absorption coefficient was measured to be 0,001 cm⁻¹ at 1064 nm. The manufacturer's specification for the absorption coefficient of the $KGd(WO_4)_2$ crystal (one of the widely used Raman crystal) is < 0,004cm⁻¹. As the absorption measurements for the present diamond sample and for the samples in [3, 7] show, the absorption loss of modern synthetic diamond can now be close to that of more conventional optical materials.
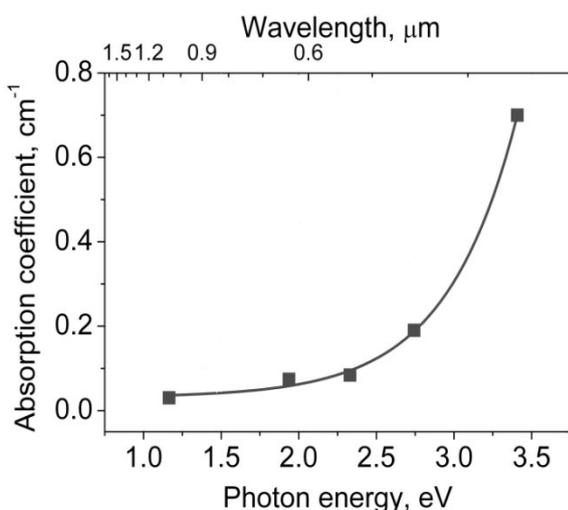

Figure 2 – Losses in diamond sample as a function of pump photon energy

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Савицкий В.Г., Кэмп А.

Упрощённый метод калориметрического измерения фоновых оптических потерь в кристаллах

Сообщается об использовании адаптированного метода лазерной калориметрии для измерения коэффициента поглощения в кристалле искусственного алмаза на длинах волн 1064, 640, 532, 452 и 364 нм. Установлено, что коэффициент поглощения материала экспоненциально возрастает от 0,03 см⁻¹ на длине волны 1064 нм до 0,7 см⁻¹ на 364 нм. (E-mail: vasili.savitski@strath.ac.uk)

Ключевые слова: калориметрический метод, оптическое поглощение, искусственный алмаз.