our future through science

An all optical system for studying temperature induced changes in polycrystalline diamond deposited on a tungsten carbide substrate

BN Masina[1], A Forbes [1,2], R Bodkin [3], BW Mwakikunga[1]
[1] CSIR National Laser Centre, PO Box 395, Pretoria, 0001, South Africa
[2] School of Physics, University of Kwazulu-Natal, Private Bag X54001, Durban 4000, South Africa
[3] Element Six (Production) (Pty) Ltd, 1Debid road, Nuffield, Springs 1559, South Africa

Email: BMasina@csir.co.za - www.csir.co.za

Introduction

“Industrial diamond” comprises a polycrystalline diamond (PCD) layer on a supporting tungsten carbide (WC) substrate that is sintered at high temperature and high pressure (HTHP); and the origin of this diamond has been discussed previously, and an inset of the industrial diamond sample used in this study is shown in the inset of Figure 1 (c).

In this poster we discussed the ability to heat an industrial diamond sample by means of optical absorption of a CO_2 laser beam, and then measure the resulting temperature on the surface of the diamond optically by means of radiometry principles. A model for the temperature on the surface of the diamond was developed and we show that it agrees qualitatively with experimental data. In particular, we show that it is possible to engineer the boundary conditions and initial beam such that uniform temperature gradients can be created, thus allowing the study of thermal effects in the absence of thermal stresses. We make use of the known grey body emission from polycrystalline diamond (PCD) [6]. We show that uniform temperature alone can account for significant structural changes in PCD diamond.

Temperature model

In order to find the dynamic temperature distribution on the surface of the sample, the heat diffusion equation was solved with a non-zero source term:

$$\frac{\partial U(r,t)}{\partial t} - D\nabla^2 U(r,t) = Q(r) \qquad (1)$$

with diffusivity $D = k/\rho Cp$, U is the temperature on the surface of the sample, ρ is the density of the diamond, k is the thermal conductivity and Cp is the heat capacity and $Q(r)$ is the source term. The source term of this study was a continuous wave laser beam of Gaussian intensity distribution, which leads to a source term given equation 2 and in case when the flat-top beam is used, the source term is given 2, respectively.

$$Q(r) = \frac{2P_0\alpha \exp\left(\frac{-2r^2}{\omega^2}\right)}{\rho l C_p \pi\omega^2} \quad \text{and} \quad Q(r) = \frac{P_0\alpha}{\rho l C_p \pi\omega^2} \qquad (2)$$

where P_0 is the total power of the laser beam, α is the absorption coefficient of the PCD sample, w is the laser beam radius at the sample and l is the laser penetration depth. In the case when the flat-top beam is used, the source term is given by: This problem can be formulated in terms of the Green’s function approach, which leads to an integral solution given by:

$$U(r,t) = \int_0^t \int_0^a Q(\xi,\tau) G(r,\xi,t-\tau)\, d\xi dt \qquad (3)$$

With

$$G(r,\xi,t) = \frac{2}{a^2}\xi + \frac{2}{a^2}\sum_{m=1}^{\infty} \frac{\xi}{J_0^2(\alpha_m)} J_0\left(\alpha_m \frac{r}{a}\right) J_0\left(\alpha_m \frac{\xi}{a}\right) \exp\left(-\frac{D\alpha_m^2 t}{a^2}\right) \qquad (4)$$

Here we have assumed that $\frac{\partial U}{\partial r} = 0$ at $r = a$, and that $U(r, 0) = 300$ K. The α_m terms are positive zeros of the first-order of Bessel function, $J_1(\alpha_m) = 0$. Here a is the sample radius, J_x refers to a Bessel function of order x, *and* r is the radial coordinate.

Experimental methods

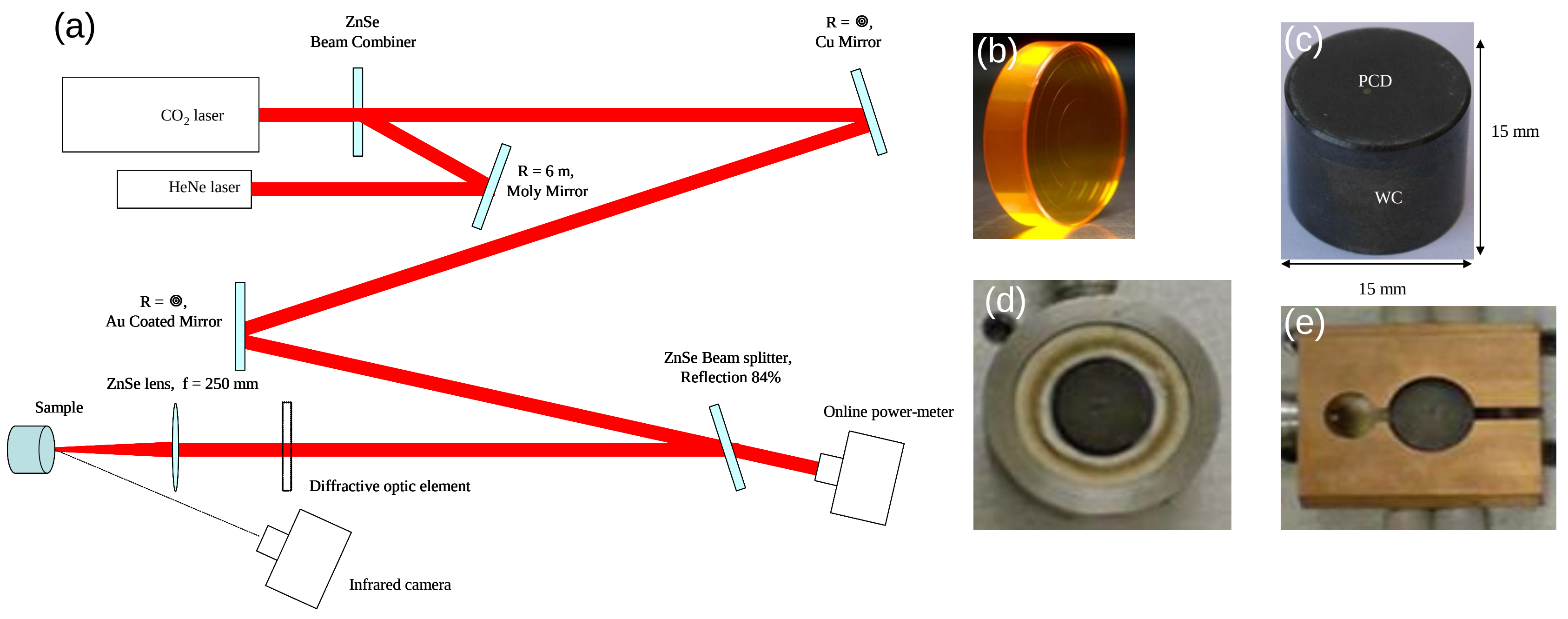

Figure 1: (a) A schematic diagram of the laser delivery system for laser heating the sample and measuring the resultant temperature profile, (b) A picture of diffractive optical element (DOE), (b) the diamond sample, (c) the insulator optical holder, and (e) the water-cooled optical holder.

References

1. B.N. Masina, A. Forbes, O.M. Ndwandwe, G. Hearne, B.W. Mwakikunga, G. Katumba, Phys. B 404, (2009) 4485
2. E.H. Bernhardi, A. Forbes, S. Bollig, M.J.D. Esser, Opt. Express 16, (2008) 11115

Gaussian beam profile

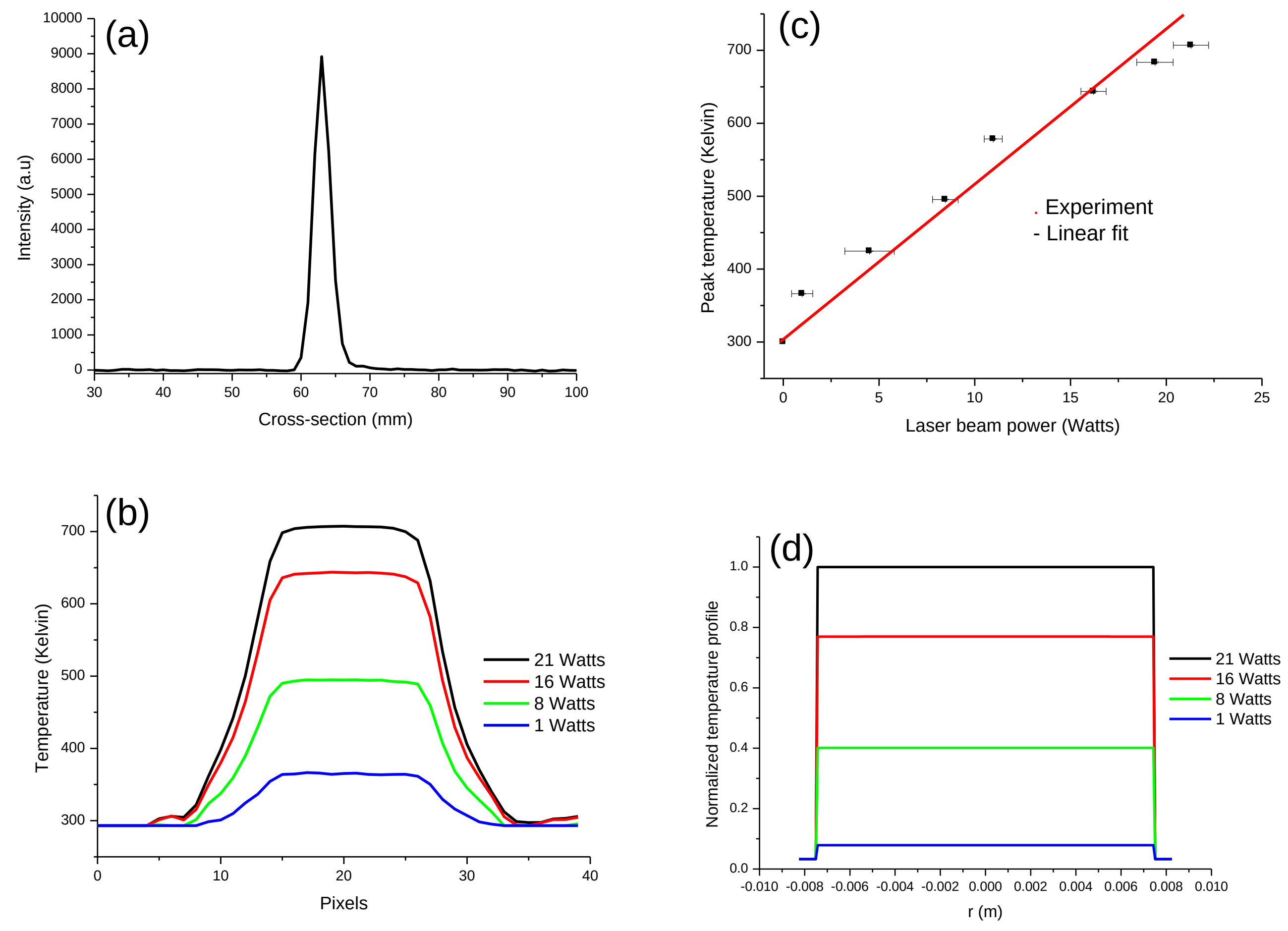

Figure 2: (a) A Gaussian beam profile, (b) At steady state the steady state the temperature profile is uniform across the sample, (c) Peak temperature increases as the laser beam power increases, and (d) the model predicted that the temperature profile across the sample is uniform.

Flattop beam profile

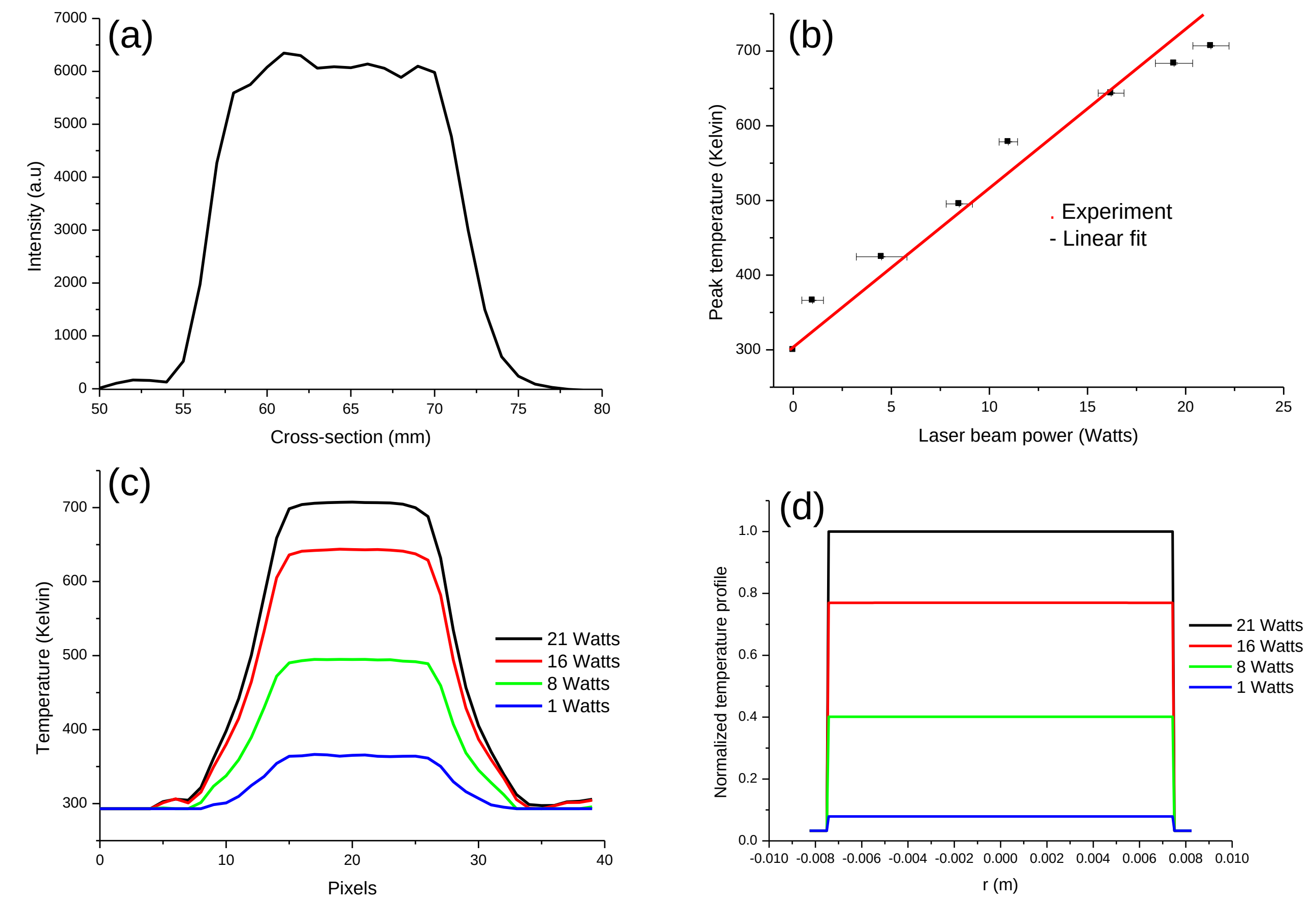

Figure 3: (a) A Flat-top beam profile, (b) At steady state the steady state the temperature profile is uniform across the sample, (c) Peak temperature increases as the laser beam power increases, and (d) the model predicted that the temperature profile across the sample is uniform.

Conclusion

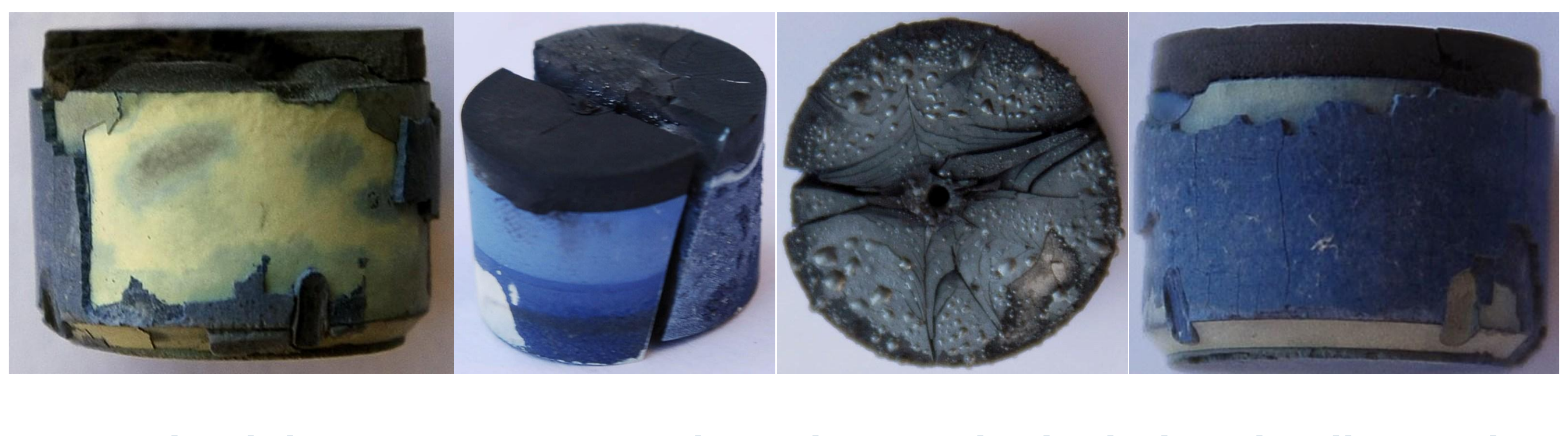

Figure 4: Indeed the temperature leads to damage in the industrial diamond and the damage is due to chemical changes and physical changes as shows in these pictures of damages industrial diamond.

We demonstrated an optical system for temperature profile, peak temperature and average temperature. The error margin of the temperature measurement was not more than 5 %. The generation of such temperature profiles on HTHP diamond in the laboratory are important to study changes that occur in polycrystalline diamond tools, particularly the reduced efficacy such tools in applications where extreme heating due to friction is expected**.**