An all-optical system designed for the heating and temperature measurement of the diamond tool

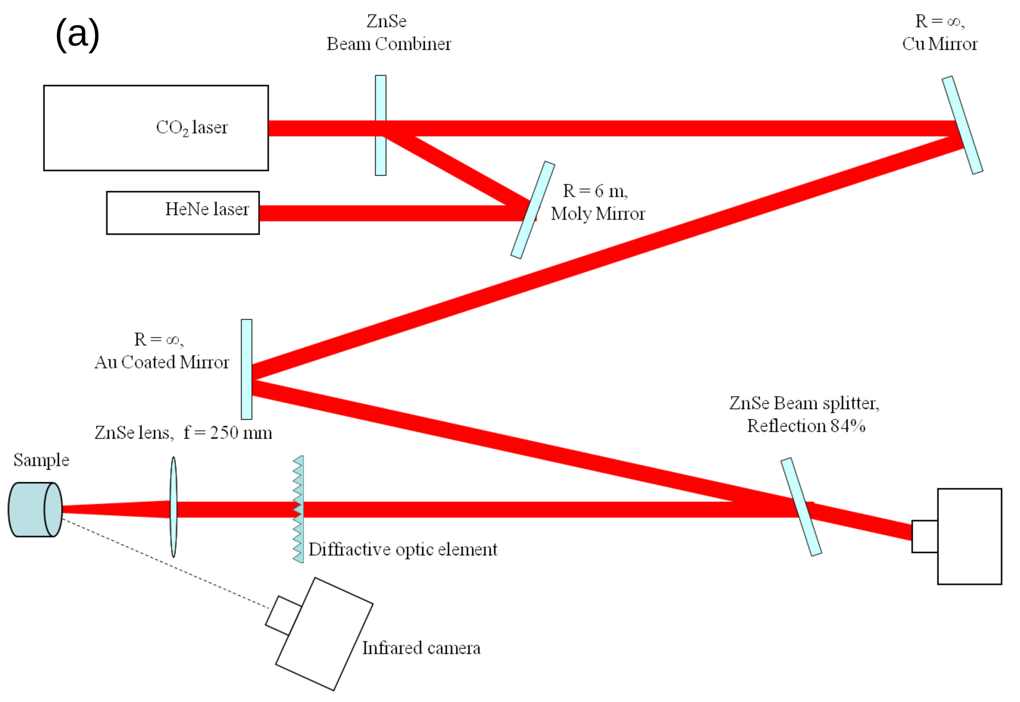
BN Masina[1,2], A Forbes [1,2], R Bodkin [3], BW Mwakikunga[1]
[1] CSIR National Laser Centre, PO Box 395, Pretoria, 0001, South Africa
[2] School of Physics, University of Kwazulu-Natal, Private Bag X54001, Durban 4000, South Africa
[3] Element Six (Production) (Pty) Ltd, 1Debid road, Nuffield, Springs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

INTRODUCTION

Diamond tools are used in industry for abrasive applications such as grinding, and drilling. One of its important applications is in drill bits used for drilling through rock in search of oil. The early failure of drill bits used in oil drilling rigs has huge financial implications. Therefore, we have undertaken a study trying to understand this problem and solving it by applying the science of light. In this work we outline how a non-contact of all-optical system was designed for the heating and then subsequent temperature measurement of the diamond tool. A laser beam was used as the source to raise the temperature of the diamond tool, and the resultant temperature was measured by using the blackbody principle. In this poster, we have successfully demonstrated temperature profiles across the diamond tool surface using two laser beam profiles and two optical setups, thus allowing a study of temperature influences with and without thermal stress. The generation of such temperature profiles on the diamond tool in the laboratory is important in the study of changes that occur in diamond tools, particularly the reduced efficiency of such tools in applications as rock drilling where extreme heating due to friction is expected. The results show that laser heating does not result in graphitization of the diamond tool, but rather cobalt and tungsten oxides form on the diamond tool surface

1. EXPERIMENTAL SET-UP

(a)



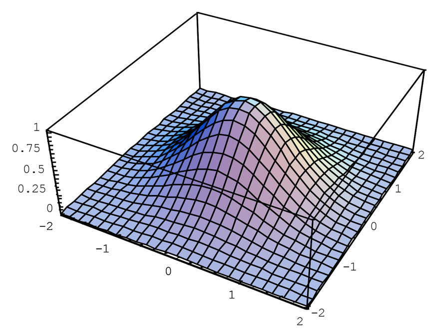
(b)

WATER-COOL CASE

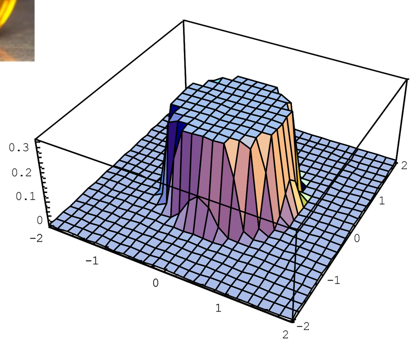
INSULATOR CASE

(c)

DOE



GAUSSIAN BEAM



FLAT-TOP BEAM

FIGURE 1: (a) A schematic diagram of the laser delivery system for the laser heating of the sample and measuring the resultant temperature profile. Our set-up makes use of CO_2 laser as a source term. (b) We created two simple holders for the object so that the two sets of experiments can be realized. (c) In this study, we used DOE as a phase element in conjunction with a Fourier transforming lens to transform a Gaussian beam profile into a flat-top beam profile as is showed in figure (a).

2. TEMPERATURE MODEL

In order to find the dynamic temperature distribution on the surface of the sample, the heat diffusion in 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 $D = K/C_p\rho$, U is the temperature on the surface of the sample, ρ is the density of the diamond, k is the thermal conductivity and C_p 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 in equation 2 (a) and in case when the flat-top beam is used, the source term is given in equation 2 (b), respectively.

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

Where P_o is the total power of the laser beam, α is the absorption coefficient of the PCD sample, ω is the laser beam radius at the sample and l is the laser penetration depth. This problem can be formulated in terms of the Green's function approach, which leads to an integral solution given by:

$$U(r,t) = \int_0^t \int_0^a Q(\xi,\tau)G(r,\xi,t-\tau)d\xi dt \quad \text{with} \quad G(r,\xi,t) = \frac{2}{a^2}\xi + \frac{2}{a^2}\sum_{m=1}^{\infty}\frac{\xi}{J_0^2(\alpha_m)}J_0\left(\alpha_m\frac{r}{a}\right)J_0\left(\alpha_m\frac{\xi}{a}\right)\exp\left(-\frac{D\alpha_m^2 t}{a^2}\right) \quad (3)$$

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, $J_1(\alpha_m)$. Here a is the sample radius, J_x refers to a Bessel function of order x ,and r is the radial coordinate.

6. REFERENCES

BN Masina et. al., "Laser beam shaping for studying thermally induced damage", Pro. SPIE Vol. 8130 81300H, 2011.
BN Masina et. al., "Thermally induced defects in a polycrystalline diamond layer on a tungsten carbide substrate', Phys. B. 404 – 4489, 2009.

3. TEMPERATURE MEASUREMENTS RESULTS

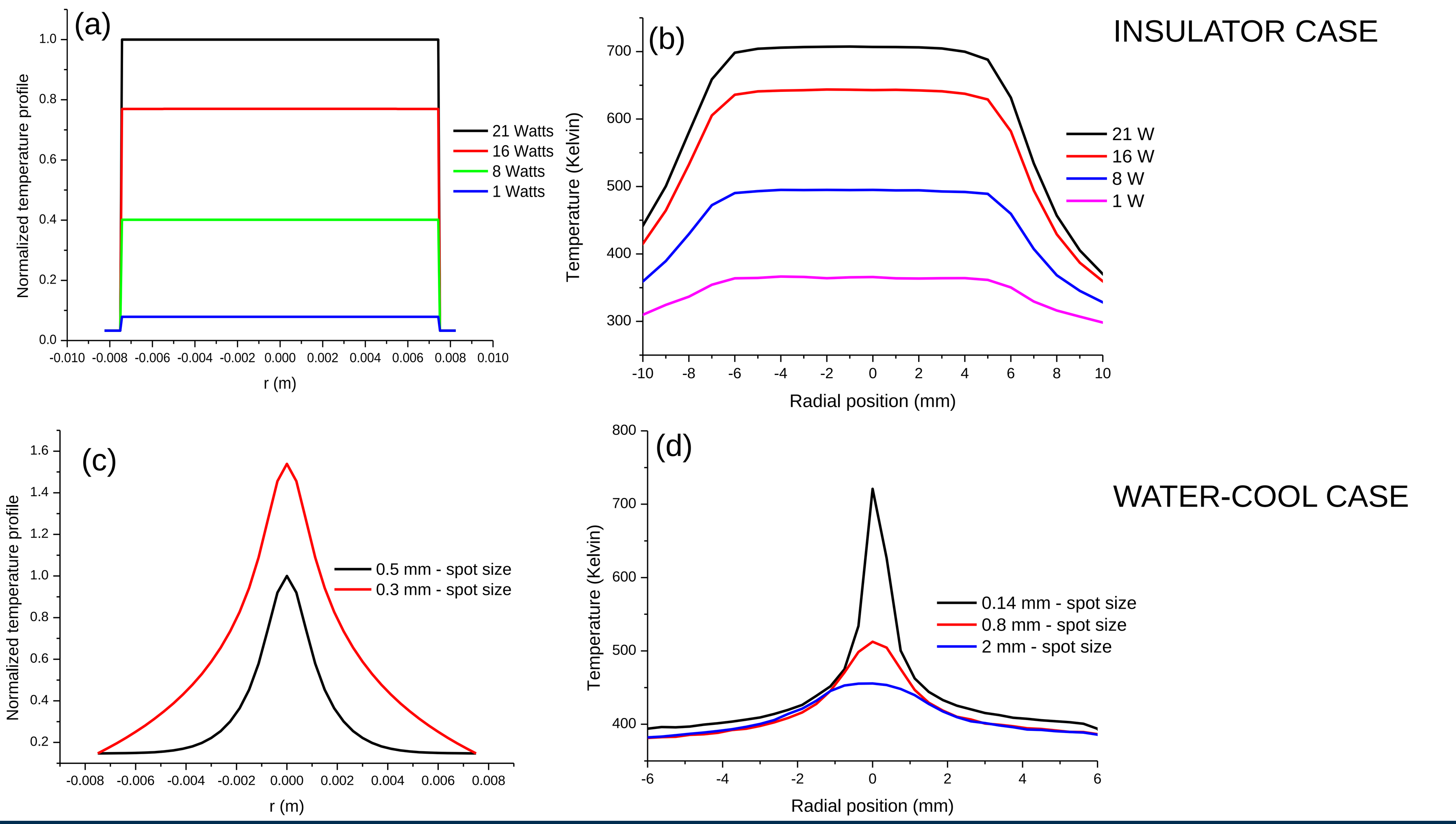
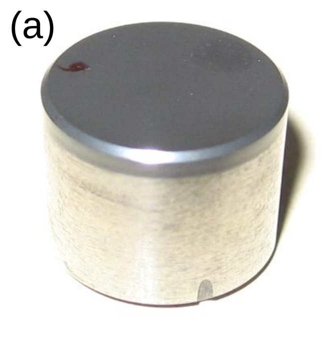


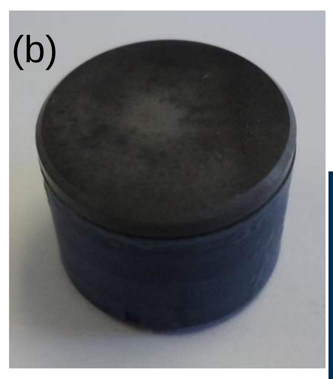
FIGURE 2: (a) Temperature profile model, (b) temperature profile across the sample surface per laser beam power that laser heated with the Gaussian and flat-top laser beam profile. (c) temperature profile model, (d) temperature profile across the sample surface per laser beam time that laser heated with the Gaussian beam profile.

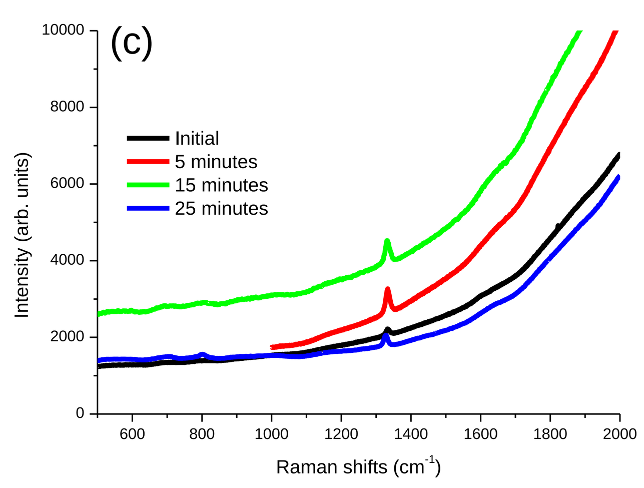
4. STRUCTURAL ANALYSIS RESULTS

(a)



(b)





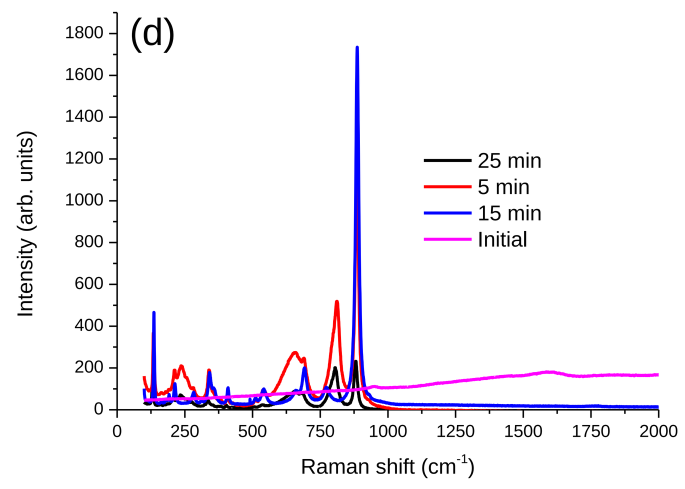


FIGURE 3: (a) Initial diamond, (b) diamond tools damaged due to the laser heating with both physical and chemical changes evident, (c) Raman shift at the diamond layer, showing the intensity of the diamond peak increases as the laser heating time increases, (d) Raman shift at the substrate of the diamond tool, after laser heating showing the tungsten oxide peaks.

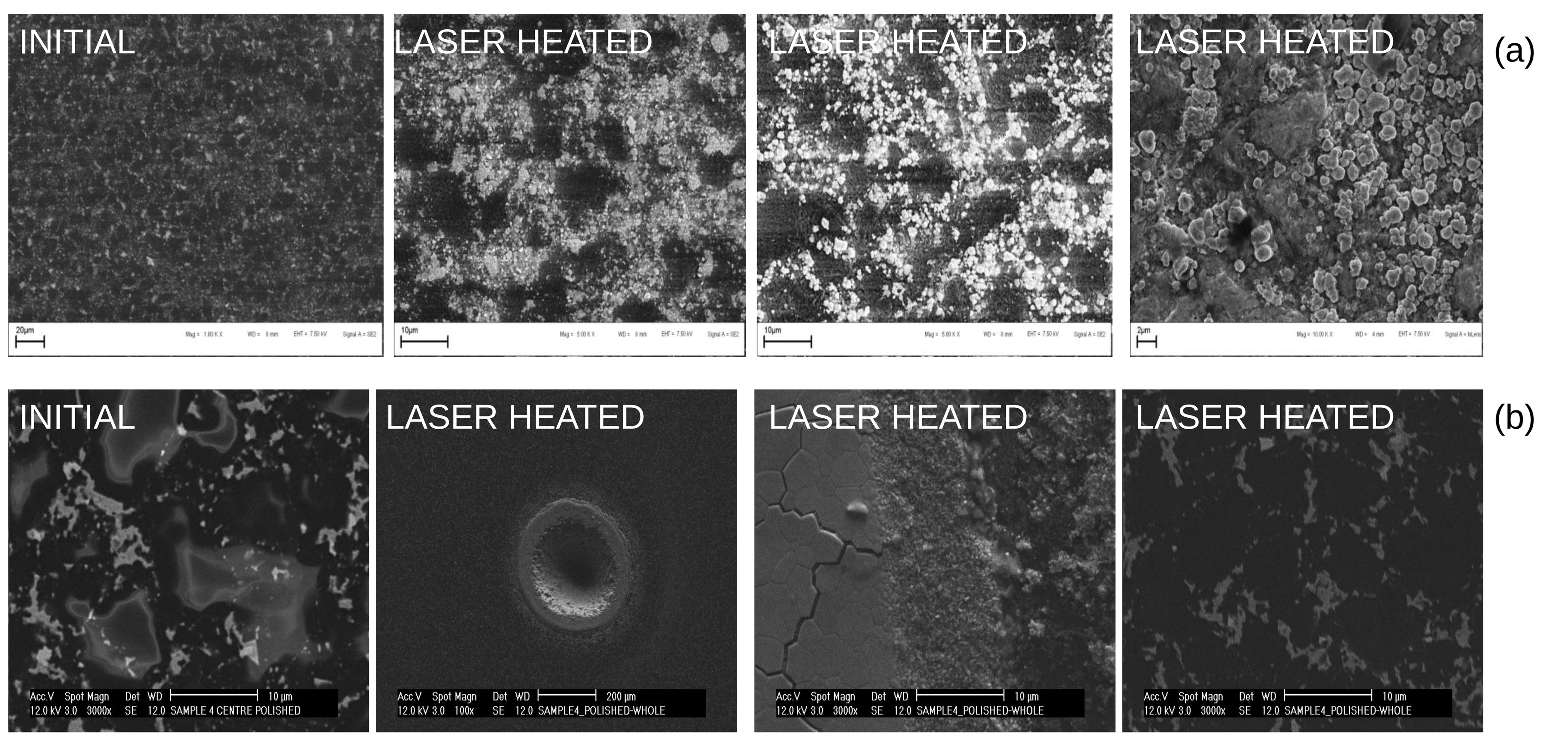


FIGURE 4: (a) SEM morphology for the Insulator case, showing an uniform damaged on the diamond layer after laser heating (Temperature across the diamond surface = 681 K, 26 W, 0.7 mm, 45 minutes). (b) SEM morphology for the water-cool case, showing only the damaged on where the laser was heating on the diamond layer (Peak temperature = 853 K, 242 W, 0.14 mm, 30 seconds).

5. CONCLUSIONS

We successfully designed an optical system to raise and measure the resultant profile temperature of diamond tool. The optical system can measure temperature ranges from room temperature to 1273 Kelvin and also this system can be use to any material. The generation of such temperature profile on diamond tool in the laboratory are important to study changes that occur in polycrystalline diamond tools, in particular the reduced efficacy of such tools in applications where extreme heating due to friction is expected.