33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Temperature Elevation inside Neural Tissue Illuminated by NIR Laser

Ammar Abdo, *Student Member, IEEE, Ali Ersen, Student Member, IEEE,* and Mesut Sahin, *Senior Member, IEEE*

***Abstract*— Near infrared (NIR) light energy has been used in medical applications both for diagnostic and treatment purposes. Temperature elevation is the main concern in the neural tissue when illuminated with NIR light. In this report, an NIR light beam was pulsed into a rat brain cortex. The spatial maps of temperature elevation inside the neural tissue were measured directly using a micro probe. The results indicate that the temperature inside the neural tissue saturates with increasing levels of laser power.**

Key Words: **near infrared light, neural stimulation laser heating.**

I. INTRODUCTION

Near infrared (NIR) light has been used in diagnostic and therapeutic medical applications such as spectroscopic imaging [1] and treatment of brain tumors [2]. It is also being tested in subretinal prostheses. In our laboratory, we are interested in wireless transportation of energy to an implantable microstimulator by optical means in the NIR wavelengths [3-5], as a method to solve the problems associated with the microelectrode arrays that have fine wire interconnects [3], [4]. Microelectrode arrays often fail due to breakage of wire interconnects and the chronic tissue response caused by the tethering force of the wires.

Light radiation into neural tissue can cause temperature elevations as a result of absorption of the photons. It was shown that an increase of 1ºC in temperature can cause profound effects in the neural tissue [6]. Optical tissue properties (scattering and absorption coefficients) and the number of photons penetrating inside the tissue determine the magnitude and spatial pattern of the temperature distribution [6]. Scattering is the dominant form of interaction with the neural tissue at NIR wavelengths. NIR light can penetrate easier into neural tissue than the visible light due to lower amount of scattering. Gray matter also has a lower scattering coefficient than the white matter, and as a result NIR light penetrates more readily into the gray matter.

The main objective of this short study was to directly measure the temperature elevation inside the rat brain under exposure to an NIR laser beam and determine the maximum allowable light power.

Manuscript received April 15 2011. This study was supported by a grant from National Institute of Health NINDS (R21 NS050757) and NIBIB (R01 EB009100).

All authors are with the Biomedical Engineering Department, New Jersey Institute of Technology, Newark, NJ 07102 USA.
Corresponding author is M. Sahin (phone: 973-596-5573, Fax: 973-596-5222, e-mail: sahin@njit.edu).

II. METHODS

A Sprague-Dawley rat (400g) was used for this study. The anesthesia was induced with ketamine (80mg/kg) and xylazine (12mg/kg) mixture diluted with saline. Ketamine was used for further doses as needed. Marcaine (0.2mL) was injected at the site of incision. The rectal temperature was continuously monitored and maintained between 35-36^{o}C using a temperature regulated heating pad. The skull was opened and brain cortex was exposed. Dehydration of brain tissue was prevented using a pool of mineral oil. All experimental procedures were approved by the Animal Care Committee at Rutgers University.

A temperature probe (T301 type thermocouple with a tip diameter of 100μm, Unisense, Denmark) was modified to reduce the response time. The glass cover was removed and a thin layer of epoxy was applied. The thermocouple wire was attached to a 125 μm thick Tungsten electrode with a sharp tip as a backbone for easy penetration into brain. The probe was inserted into the brain at an angle of 45 degrees using a 3-axis micromanipulator. The laser source (DLS-500-830FS-100, StockerYale, Canada, 74mW) and acquisition of the signals into the computer were controlled by a custom MATLAB program. The laser was placed 13.5cm above the brain using another micromanipulator and aimed at the sensor from above (Fig. 1). A train of NIR pulses (3 ms pulse width, 100Hz, 10s train duration) were sent to the probe with a circular footprint of 0.56 mm in diameter at the cortex surface. The temperature was measured at different depths (250-3250μm in steps of 250μm). For each depth of the sensor position, the laser beam was horizontally moved up to 1200μm from the origin in steps of 100μm.

A commercial photodiode (circular active area, ø0.1mm) was used to verify the laser profile shown in Fig. 2. The profile is Gaussian with a circular cross section. The radius was taken at $\sqrt{2}\sigma$, which is the horizontal distance where the Gaussian intensity profile drops down to $1/e^2$ of its peak in 2D plane. This diameter is that of a flat profile beam with the same peak power intensity and the same total power as our Gaussian profile laser. The total light power sent into the brain was calculated by multiplying the duty cycle (0-35%) with the instantaneous output power of the laser (76mW).

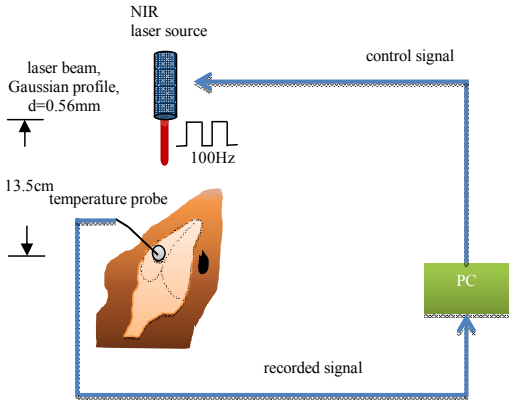

Fig. 1. A sketch of the preparation used to measure the temperature increase due to light radiation in the rat brain.

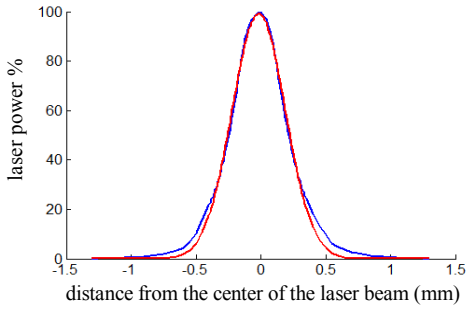

Fig. 2. Light intensity profile at 13.5cm from the laser source. Experimental data is in blue, and curve fit is in red.

III. RESULTS

Figure 3 shows the raw temperature signal with the sensor in the brain gray matter at a depth of 500μm. The temperature first increases very rapidly and then stabilizes slowly at about 35.3ºC before the laser is turned off at t=10 seconds. Figure 4 shows the temperature elevation inside the brain at the surface and at a depth of 1.5mm as a function of laser power. The temperature increases almost linearly first and then plateaus at around 36.3ºC and 34.8ºC at the surface and at 1.5mm respectively. The map of temperature elevations within the 2D vertical plane is shown in Fig. 5. Temperature profile drops quickly in the horizontal direction almost following the same course as the laser intensity profile. In the vertical direction, however, it extends a few times the laser diameter.

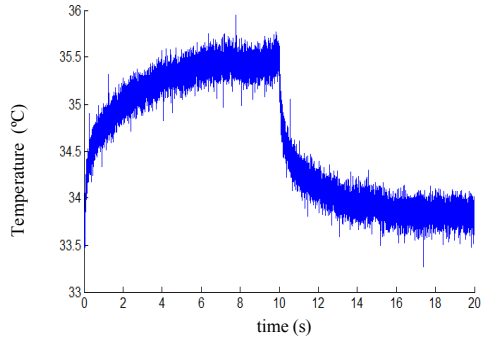

Fig. 3. An example of temperature signal produced as a response a 10s long laser pulse train. Relative temperature increase was obtained by filtering the signal from thermal noise and then sampling the noise-free plot at 10 and 20 seconds. Measurements were obtained at a depth of 500 μm.

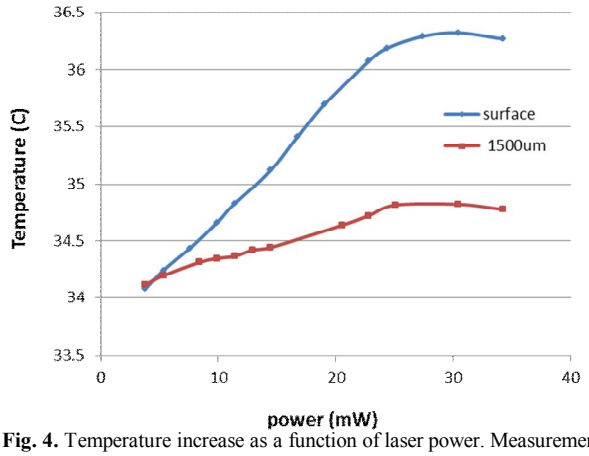

Fig. 4. Temperature increase as a function of laser power. Measurements were obtained at the surface (blue) and at a depth of 1.5mm from the pial surface (red).

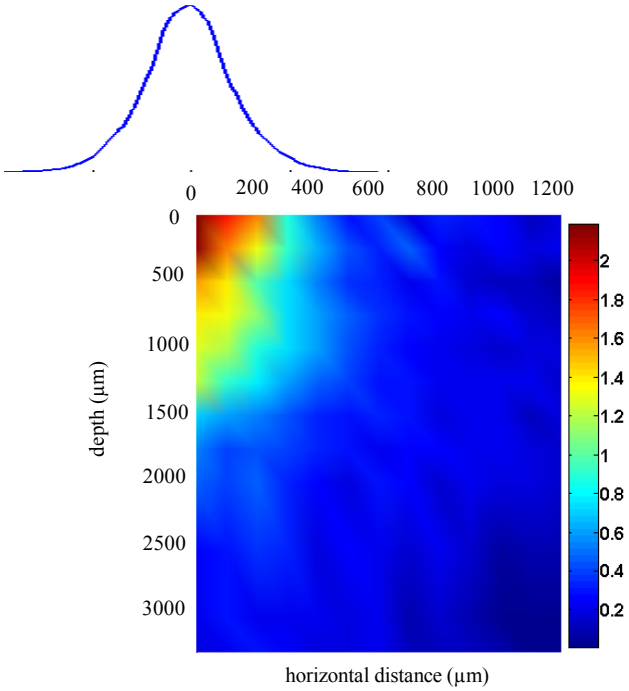

Fig. 5. 2D temperature elevation inside the rat brain due to a laser illumination of 23mW. Measurements were made in steps of 250μm vertically and 100μm horizontally and then interpolated for intermediate points. Note that vertical and horizontal axes are not on the same scale. The bell shaped curve above shows the laser intensity profile alignment with respect to the 2D temperature plot.

IV. Discussion

In this report, temperature elevations inside the rat brain (gray matter) was measured while being radiated by a beam of NIR laser. Figure 4 showed that the rate of temperature rise slows down above certain temperature of elevation, at which point perhaps some biological mechanism begin to regulate the local temperature. Figure 5 shows that the spatial gradient of temperature is smaller vertically than horizontally. This must be due to the fact that the beam is entering the medium in the vertical direction.

The power used to illuminate the neural tissue was 23mW, which caused a temperature increase of 2.2ºC near the surface. Sailer *et. al.* reported a temperature rise of 3.2ºC when illuminating a subretinal implant with infrared power of 15mW (4.8mW/mm^2) inside a rabbit's eye [7].

In neural tissue however, a temperature rise of 1ºC can be harmful [6]. In this report, a laser power of 9mW caused a temperature elevation of 1ºC which is considered our maximum tolerable light power. This amount of power is several times higher than what was used in our laboratory to activate wireless microstimulators implanted in the cervical region of rat spinal cord [5].

The beam profile is a critical factor to keep the temperatures below a certain limit in the neural tissue. A Gaussian profile circular beam, for instance, would have a peak of $1/(2\pi\sigma^2)$ times the total power of the source. For small diameter beam sizes, the profile can be very peaky and therefore easily induce large temperature elevations in the center of the beam. A flat profile circular beam, which can be obtained with the use of optical microlenses, can avoid the spatial peak effect.

Acknowledgment

This study was funded by National Institute of Health/NINDS (R21 NS050757) and NIBIB (R01 EB009100).

References

[1] F. W. Koehler IV, E. Lee, L. H. Kidder, and E. N. Lewis, "Near Infrared Spectroscopy: the Practical Chemical Imaging Solution," *Spectroscopy Europe*, vol. 14, 2002.

[2] Z. Amin, J. J. Donald, A. Masters, R. Kant, A. C. Steger, S. G. Bown, and W. R. Lees, "Hepatic Metastases: Interstitial Laser Photocoagulation with Real-time US Monitoring and Dynamic CT Evaluation of Treatment," *Radiology*, Vol 187, 1993.

[3] K. Gray and M. Sahin, "Floating Light Activated Micro-Electrical Simulators", 35th Neural Interface Workshop, Bethesda, MD, Sept 2004.

[4] A. Abdo and M. Sahin, "Feasibility of neural stimulation with floating-light-activated microelectrical stimulators," *IEEE Transactions on Biomedical Circuits and Systems,* vol. 5, 2011.

[5] A. Abdo, M. Sahin, D. S. Freedman, E. Cevik, P. S. Spuhler, and M. S. Unlu "Intraspinal stimulation with light activated micro-stimulators" in the *5th International IEEE EMBS Neural Engineering Conference*-Proceedings, 2011.

[6] M. M. Elwassif, Q. Kong, M. Vazquez, and M. Bikson, "Bio-heat transfer model of deep brain stimulation-induced temperature changes," *Journal of Neural Engineering,* vol. 3, 2006.

[7] H. Sailer, K. Shinoda, G. Blatsios, K. Kohler, L. Bondzio, E. Zrenner, and F. Gekeler "Investigating of thermal effects of infrared lasers on the rabbit retina: a study in the course of development of an active subretinal prostheses," *Graefe's Arch Clion Exp Opthalmol,* vol. 245, 2007.