World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:4, No:4, 2010

Thermo-Mechanical Characterization of Skin Laser Soldering using Au Coated SiO_2 Nanoshells

M.S.Nourbakhsh,M.E.khosroshahi

***Abstract*—**Gold coated silica core nanoparticles have an optical response dictated by the plasmon resonance. The wavelength at which the resonance occurs depends on the core and shell sizes, allowing nanoshells to be tailored for particular applications. The purposes of this study was to synthesize and use different concentration of gold nanoshells as exogenous material for skin tissue soldering and also to examine the effect of laser soldering parameters on the properties of repaired skin. Two mixtures of albumin solder and different concentration of gold nanoshells were prepared. A full thickness incision of 2×20 mm^2 was made on the surface and after addition of mixtures it was irradiated by an 810nm diode laser at different power densities. The changes of tensile strength σt due to temperature rise, number of scan (N_s), and scan velocity (V_s) were investigated. The results showed at constant laser power density (I), σt of repaired incisions increases by increasing the concentration of gold nanoshells, N_s and decreasing V_s. It is therefore important to consider the trade off between the scan velocity and the surface temperature for achieving an optimum operating condition. In our case this corresponds to σt =1610 gr/cm^2 at I~ 60 Wcm^{-2}, T ~ 65ºC, N_s =10 and V_s=0.2mms^{-1}.

***Keywords*—**Tissue soldering, Diode laser, Gold Nanoshells, Tensile strength

I. Introduction

LASER-assisted tissue closure in skin has been investigated in recent decade [1]. Laser soldering is based on applying some soldering material (such as albumin) onto the approximated edges of the cut and heating the solder (and the underlying tissues) by a laser beam. Laser tissue soldering (LTS) using a diode laser and an indocyanine green (ICG)/albumin solder has been shown to be an effective technique in surgical reconstruction by providing a watertight sealant with minimal damage to underlying tissue [2]. Decoste et al [3] and Bass et al [4] have shown that ICG is an effective chromophore for this purpose. Laser tissue soldering (LTS) has been successfully utilized in anastomoses of various tissues including the gastrointestinal tract [5], blood vessels [6], cartilage [7] and skin [8], [9].

The change of solder color during the heating process has an effective role in determining of the completion of LTS when ICG is a solder chromophore component.

Nanoshells are a new class of nanoparticles consisting of a dielectric core surrounded by a thin metal shell. In the current work, nanoshells with a silica core and gold layer are used. The plasmon resonance of these nanoparticles can be tailored by varying the ratio of the diameter of the core to the thickness of the shell [10]. Through design and control of the particle geometry, nanoshells can be tuned to absorb at a wide range of wavelengths from the visible into the NIR, allowing the material's optical properties to be tuned to match the output of a desired laser.

Nanoshells are currently being used for a variety of biomedical applications and have been shown to be non toxic and highly biocompatible [11]. For example, in a cancer therapy application, nanoshells have been injected systemically, accumulated within tumors due to vascular permeability, and then used for photo thermal ablation due to their ability to rapidly heat upon exposure to near infrared light [12].

The use of nanoshells has several advantages over ICG. The average diameter of nanoshells is about 100 nm so that reduced diffusion from the site of treatment and concentrating heating at the interface is avoided, which should in effect the minimize damage to surrounding tissue. Hence another advantage of nanoshells is that they are more photo-stable since their absorption properties are determined by their physical structure. Additionally, nanoshells are more strongly absorbing than ICG on a per particle or molecule basis. Indocyanine green has an absorption cross-section on the order of ~$10^{-20}m^2$, while nanoshells have absorption cross-section on the order of ~10^{-14} m^2, so nanoshells are approximately a million-fold more effective absorbers [13]. In the previous work we used an 810 nm diode laser with the combination of ICG and BSA as biological solder of skin incision [9]. The purpose of this study is to evaluate the effect of different concentrations of gold nanoshells and laser processing parameters on the quality of repaired skin.

M. S. Nourbakhsh is with the Laser and Nanobiophotonics Lab., Biomaterials Group, Faculty of Biomedical Engineering, Amirkabir University of Technology, Tehran, Iran (e-mail: s_nourbakhsh@ aut .ac .ir).

M. E. Khosroshahi is with the Laser and Nanobiophotonics Lab., Biomaterials Group, Faculty of Biomedical Engineering, Amirkabir University of Technology, Tehran, Iran (Corresponding author to provide phone: +982164542398;fax:+982166468186;e-mail: khosro @ aut .ac .ir).

II. Materials And methods

Gold nanoshells synthesis and characterization

Silica cores were first grown using the Stober method, based on reduction of tetraethyl orthosilicate (TEOS) (Sigma-Aldrich's. Louis, MO).The resultant silica nanoparticles were sized using atomic force microscopy (Dual scope/ Raster scope C26, DME, Denmark). Addition of 3-aminopropyl trimethoxysilane (APTMS, Sigma-Aldrich, St. Louis, MO) to silica core provided amine groups on the surface of the core for deposition of gold colloid. Gold colloid was prepared with a size range of 2–4 nm using the method described by Duff et al. [10]. The colloid was then concentrated and mixed with the aminated silica particles allowing small gold colloid to attach to the larger silica nanoparticles surface in order to act as nucleation sites in the subsequent reduction step. The gold shell was then grown by the reduction of gold from $HAuCl_4$ in the presence of formaldehyde. The gold is reduced around the initial colloid sites, coalescing to form a complete shell. Absorption characteristics of the nanoshells were determined using a UV-Vis spectrophotometer (Philips UV/VIS-spectro-photometer PU 8620).

In-vitro skin soldering

A 40×50 cm^2 fresh piece of sheep skin was obtained from slaughter house and depilated suitably and cut into pieces of 4×5 cm^2. The prepared samples were stored in refrigerator until required. After preparation, a full thickness cut of 2×20 mm^2 was made on the skin surface using 11" blades. Protein solder solution was prepared with using 25% BSA (Sigma Chemical Co.) and two different concentrations of gold nanoshells mixed in HPLC grade water. The set up of laser soldering system is shown in Figure 1.The system includes the following: (1) a tunable CW 1.5-6W diode laser with a peak emission at 810 nm with a rectangular beam profile with dimensions of 1×7mm^2, (2) a scanning system that moves the skin surface under laser probe with variable speed, (3) a digital thermometer (CHY502A1, Taiwan) that measures the skin temperature rise during laser soldering, (4) computer analysis of thermometer signals and recording system .

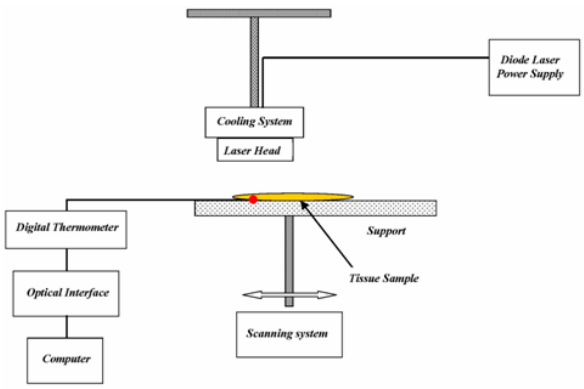

Fig.1 Experimental setup for in-vitro laser soldering of skin. The system includes :(1) 810 nm diode laser, (2) scanning system, (3) digital thermometer, (4) computer.

For each concentration of nanoshells, the mixture of nanoshells and BSA Solder (50µl) was applied to the cut edges, and the edges were brought into contact with one another and then irradiated with different power densities in the dynamic mode. In this procedure, the laser probe was located perpendicularly to the incision and scanning system scanned the surface with a predefined speed until the soldering was completed. The temperature rise at the skin during the irradiation was measured with a digital thermometer. The laser beam moved from one place to the next, along the cut line, so that each line slightly overlapped the previous one. Tensile strength measurements were performed to test the integrity of the resultant repairs immediately following the laser procedure using a load machine (Zwick/Roell, HCT 25/400 series). Strips were inserted into the head of loading machine and tensile strength measurement was carried out at a rate of 2mm/min. For comparison of results, the P-values for the differences between different concentrations were calculated by using the one-way analysis of variance (ANOVA) test. Statistically significant differences were considered as $P<0.05$.

III. Results and disscussion

Tensile strength of repaired specimens were measured as a function of laser irradiance and the concentration of gold nanoshells, see figure 2. Each tensile strength (σ) value of laser treated samples was determined from the mean of 5 repaired cuts. As it is seen from the figure 2, not only the value of σ increases with power density but also increases with increasing the concentration of nanoshells. But for the latter case, the difference is not statistically significant (P-value=0.52).

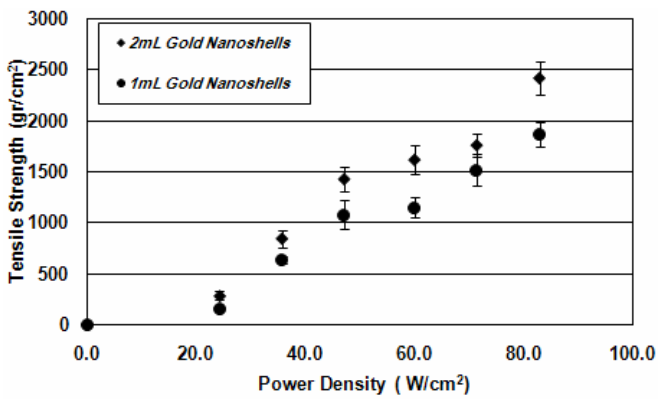

Fig. 2 Variation of tissue tensile strength with laser power densities at constant nanoshells concentration.

Tissue temperature rise as a function of laser power density for different nanoshell concentrations is shown in fig.3, where each peak was observed when the laser beam was coincided with the tip of thermometer.

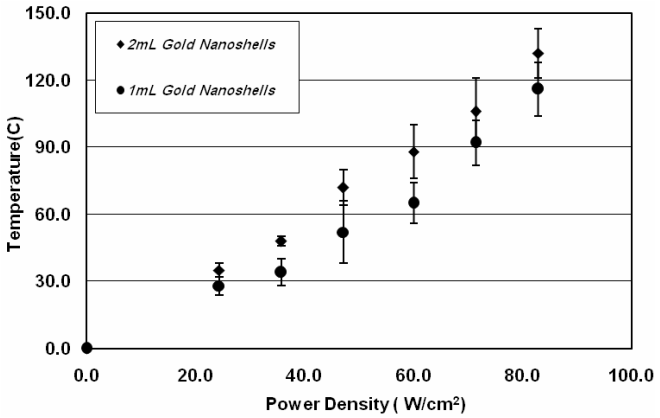

Fig. 3 Tissue surface temperature rise as a function of laser power density.

The effect of number of scans (N_s) on the tensile strength of repaired skin for two different concentrations at constant irradiance (83W/cm^2) is illustrated in figure 4. For the given irradiance, tensile strength increases by increasing the number of scans which may be explained by the fact that not only the depth of thermal denaturation increases with temperature rise, also by overlapping tales of thermal signals before the complete cooling of scanned region. Figure 5 indicates that at constant I, increasing Vs cause the corresponding value of σ to decrease due to lower temperature rise.

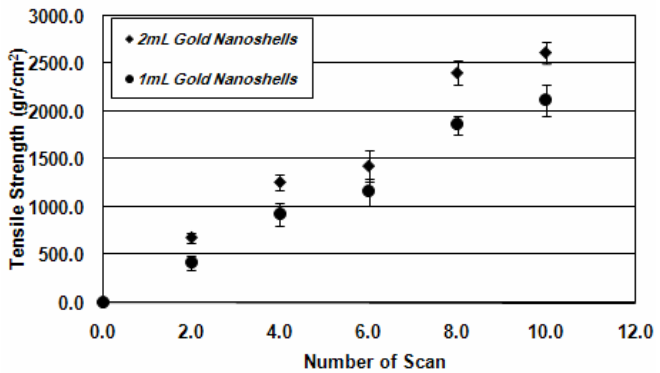

Fig.4 Effect of number of scans and nanoshells concentration on tissue tensile strength at a given power density.

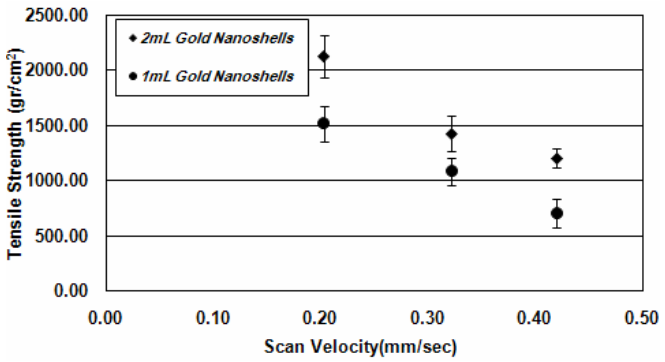

Fig. 5 Effect of laser scans velocity on tissue tensile strength at a given power density.

Examples of tissue before and after soldering at 60W/cm^2 are shown in figure 6. It is clearly seen that the incision is completely closed and there after it is expected that the process of wound healing to take place.

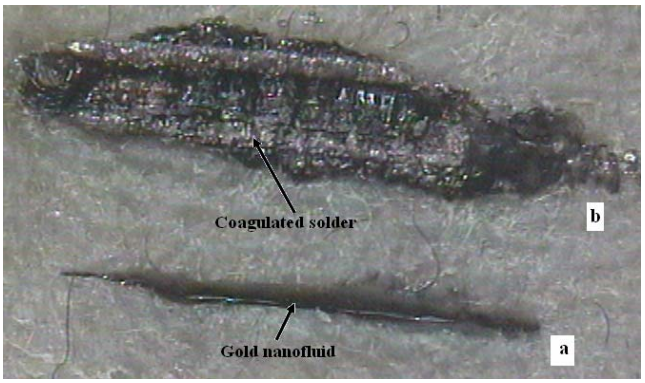

Fig. 6 An example of skin tissue before and after laser soldering at I=60W/cm^2.(a) Incision plus nanofluid before soldering and (b) incision and nanofluid after soldering.

Using of lasers with wavelengths in the NIR for tissue soldering has distinct advantages. Higher laser power and deep penetration can be achieved because hemoglobin, melanin, and water have low absorption coefficients in the region between 650 and 900 nm [13]. Thermal penetration depths of several centimeters in the above range have been demonstrated in breast tissue as well as brain [14]. In a study by Kirsch et al. [15], temperatures during laser activation with an ICG/albumin solder were determined within the solder and underlying dermis over 1 minute of activation. The results showed temperature within the solder reached 101.1°C, while temperature in the superficial and deep skin was 69.9 and 65°C, respectively. Also, our previous work [9] ,[16] showed that maximum tensile strength of repaired tissue achieved by ICG was ~ 2000 gcm^{-2} which is less than the value obtained by gold nanoshells(~2500 gcm^{-2}).

In the current study, we have synthesized and used gold nanoshells, as an exogenous near infrared absorber for laser-tissue soldering. The nanoshells used in our experiments had a diameter of ~100 nm and a shell thickness of~10 nm. The optical properties of nanoshells are well predicted by Mie scattering theory [17], thus allowing one to calculate the dimensions of core and shell required to fabricate nanoshells with strong absorption at a given wavelength. This allows facile tuning to match the output of a desired laser source for a given application.

The objects of this research was to study the effect of gold nanoshells as the light absorbing dye for enhancement of selective photo thermal interaction on thermal and biomechanical properties of skin tissue. Our results indicate that laser power density is an important parameter during the laser tissue soldering affecting the extend of wound repair where temperature plays a crucial role. The results showed that the tensile strength of repaired wound was increased by increasing the irradiance in both concentrations of gold nanoshells. But in doing so the corresponding temperature

was also increased. What the preferred tissue temperature should be, at least during an in-vitro operation, remain controversial, varying along the above parameters with apposition pressure, tissue type and chemical composition and likely age of the tissue.

Clearly each scan can contribute to temperature rise by an increment acting as residual heat which accumulates on the previous scan effect. This, in turn implies that by varying the scanning velocity the distance between peaks and their amplitude can change, hence governing the control of the final temperature rise between two set limits.

IV. Conclusion

In summary, gold nanoshells based on silica dielectric with diameters ranging from 90 to 110 nm are fabricated where the shell thickness and roughness were controlled by the amount of TEOS and checked by AFM. Since the gold layer thickness and the LSPR effect controls the range of light absorption, thus one should clearly decide whether to choose a laser wavelength close to nanoparticles absorption peak with a lower penetration depth in tissue or requires a higher penetration depth at slightly higher wavelengths such as NIR with some absorption loss due to deviation from nanoshells resonance peak. Gold nanoshells can be a suitable alternative for ICG in tissue soldering with promising results. The results of this study showed that the tensile strength of the repaired skin increases with increasing the irradiance in both concentrations of gold nanoshells. But the concentration of gold nanoshells does not significantly affect the tensile strength. Also, by increasing the scan velocity the tensile strength of repair and operation time decreases which should be taken into account in any operation. Thus, it can tentatively be concluded that since the skin temperature should not exceed ~80ºC at any time of work, then the acceptable conditions in our experiment would correspond to I~60 Wcm^{-2}, σ=1600 gr/cm^2 , Ns =10 , Vs=0.2mms^{-1}.

References

[1] M.Gulsoy , Z.Dereli , H.Tabakogh, “closure of skin incisions by 980 nm diode laser welding”. *Lasers Med Sci* ., vol.2, no.1, pp. 5-10 2006.

[2] M.McNally, B.S.Sorg , E.K.Chan , A.J.Welch , J.M.Dawes, “Optimal parameters for laser tissue soldering. Part I: Tensile strength and scanning electron microscopy analysis”. *Lasers Surg Med.*, vol. 26, no.4, pp. 346 - 356,2000.

[3] S.D. DeCoste, W. Farinelli, T. Flotte, R.R. Anderson , “Dye enhanced laser welding for skin closure”. *Lasers Surg Med*., vol. 12, no.1, pp. 25-32,1992.

[4] L.S. Bass , “Laser tissue welding: A comprehensive review of current and future clinical applications”, *Lasers Surg Med., vol.17, no.4, pp.*315-349, 1995.

[5] D.Spector, Y.Rabi, I.Vasserman, ,A. Hardy, J.Klausner,A. Katzir, “ In vitro large diameter bowel anastomosis using a temperature controlled laser tissue soldering system and albumin stent”,*Lasers Surg Med*., vol. 41, no.7, pp.504-508,2009.

[6] A.C.O'Neill, J.M.Winograd, J.L.Zeballos, M.A.Randolph, K.E.Bujold, I.E.Kochevar, R.W.Redmond, “Microvascular anastomosis using a photochemical tissue bonding technique”. *Lasers Surg Med*., vol.39, no.9, pp. 716 – 722,2007

[7] B.Zuger, B.Ott, Th. Schaffner, J.Clemence, “ Laser solder welding of articular cartilage: Tensile strength and chondrocyte viability”. *Lasers surg Med* ., vol.28, no.5,pp.427-434,2001.

[8] D.Simhon, M. Halpern.,T. Brosh, T.Vasilyev, N.Kariv, R.Argaman, A.Katzir , “In vivo laser soldering of incisions in juvenile pig skin, using GaAs or CO2 lasers and a temperature control system”, SPIE Proc. vol. 5312, pp.162–175,2004.

[9] M.E.Khosroshahi, M.S.. Nourbakhsh, S. Saremi, F. Tabatabaee F, “Characterization of skin tissue soldering using diode laser and ICG: In-vitro studies”, *Laser Med Sci*., vol.25,no.2, pp.207-212, 2010.

[10] D.Duff, A.Baiker,P.Edwards, “A new hydrogel of gold cluster formation and particle size variation”, *Langmuir,* vol.9, no.9, pp.2301-2309,1993.

[11] J.M. Stern, J.Stanfield ,W. Kabbani , “Selective prostate cancer thermal ablation with laser activated gold nanoshells”. *J Urol*., vol. 179, no.2, pp.748–753,2008.

[12] Y.Wang, W.Qian, Y.Tan , “A label-free biosensor based on gold nanoshell monolayers for monitoring biomolecular interactions in diluted whole blood*”. Biosens Bioelectron* vol.23, no.7, pp.1166–1170, 2008.

[13] L.R.Hirsch, R.J. Stafford, J.A. Bankson, S.R. Sershen, B.Rivera,R.E.Price, J.D.Hazle , N.J.Halas, J.L.West , “Nanoshell-mediated near-infrared thermal therapy of tumors under magnetic resonance guidance” , *Proc. Natl.Acad .Sci. USA*,vol. 100, no.23,pp.13549–13554, 2003.

[14] D.P.O’Neal , L.R.Hirsch , N.J.Halas, J.D. Payne ,“Photothermal tumor ablation in mice using near infrared-absorbing nanoparticles”, *Cancer Lett* ., vol. 209, no.2, pp.171–176.2004.

[15] D.K. Dew, R.Serbent, W.S.Hart, G.C. Boynton, J.D.Byrne ,J.G.Evans “Laser assisted microsurgical vessel anastomosis techniques: The use of argon and CO2 lasers”. *Lasers Surg Med* , vol.3, no.2, pp.135-137, 1983.

[16] M.S.Nourbakhsh, M.E.Khosroshahi,, S. Saremi, F. Tabatabaee F., “ Effect of static and dynamic modes on laser tissue soldering: an in-vitro study”, NBC proceedings vol.20, pp.2383-385, 2008.

[17] R.A.Alvarez-Puebla, D.J.Ross, G.A.Nazri, R.F.Aroca , “Surface-Enhanced Raman Scattering on Nanoshells with Tunable Surface Plasmon Resonance”, *Langmuir* , vol.21, no.23, pp. 10504-10508, 2005.