STSM REPORT

STSM Application number: COST-STSM-BM1205-35950

STSM Grantee: Prof. Adam Cenian

STSM title: Temperature depth profiling of human skin in-vivo using 532 nm, 970 nm, and 1064 nm lasers

Home Institution: The Szewalski Institute of Fluid-Flow Machinery Polish Academy of Sciences

Host Institution: Jozef Stefan Institute, Ljubljana (SI),

STSM period: 2017-02-14 to 2017-02-20

STSM purpose: The purpose of the proposed STMS is to compare performance of a novel LED-based 970-nm laser, recently developed at IMP, Gdansk, to commonly used KTP (532-nm) and Nd:YAG (1064-nm) medical grade lasers. Specifically, temperature depth profiles resulting from the laser irradiation of skin were determined in-vivo by the pulsed photothermal radiometry (PPTR) technique. This provided a direct assessment of the laser energy deposition in human tissues.

Description of the work carried out during the STSM:

During the COST-STSM-BM1205-35950 the following works have been carried out:

- experimental setup was prepared and aligned in order to provide similar conditions for irradiation of each participants of the study. Figure 1 shows the set-up;

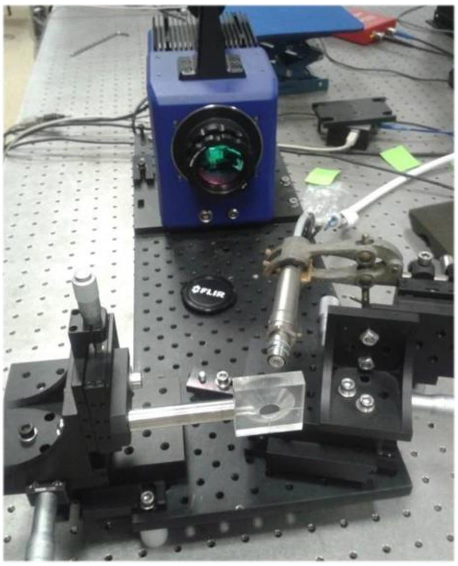

Figure 1: A photo of the experimental setup used to perform the PPTR measurements. The setup involves a fast MIR camera (SC7600, FLIR, Oregon, USA), a laser hand-piece for focusing the laser light, an acrylic sample holder with 12 mm aperture and mechanical elements for aligning other components.

- skin of 7 healthy volunteers (after checking their consent) have be irradiated using pulsed (5 ms) 970-nm diode laser (custom made), Nd:YAG (1064-nm, Dualis, Fotona, Slovenia) and KTP (532-nm, Dualis, Fotona, Slovenia) medical grade lasers. For each volunteer, the same skin region (volar side of a forearm close to an elbow) was irradiated by all three lasers and radiometric signals were recorded by IR camera (SC7600, FLIR, Oregon, USA); the measurements were repeated for five times on each spot and for each laser; an example of the PPTR signals and corresponding temperature depth profiles is presented in Figure 2.

- diffuse reflectance spectra (DRS) in the 400-1000-nm region were recorded from the same region of irradiated skin using an integrating sphere (ISP-REF, Ocean Optics, Florida, USA), a 50 μm core optical fiber and an USB spectrometer (USB 4000, Ocean Optics, Florida, USA); Figure 3 shows an example of a DRS measured on the same site as the presented PPTR signals (Figure 2a).
- temperature depth profiles were reconstructed from the recorded radiometric signals using an inverse algorithm for heat and IR light transport, i.e. pulsed photothermal radiometry approach (PPTR).[1] PPTR utilizes time-resolved acquisition of infrared radiation from a sample irradiated by a short laser pulse to obtain a laser-induced temperature profile within the sample;
- the recorded DRS spectra were analyzed using inverse Monte Carlo method and concentration of tissue chromophores, including oxygenated and deoxygenated hemoglobin, water and lipids were determined.[2] The determined concentrations helped to interpret the obtained temperature depth profiles and improve the comparison between the three laser performances;
- additionally, skin of 2 volunteers (prof. Cenian and dr. Milanic) has been irradiated using 975 nm and later, after 30 min. 940 nm new cw diode laser for approx. ½ min and radiometric signals were recorded. Later, diffuse reflectance spectra (DRS) in the 400-1000-nm region were recorded from the same region of irradiated skin; the radiometric signals were analyzed using light-heat transport model and the DRS spectra by the inverse MC.

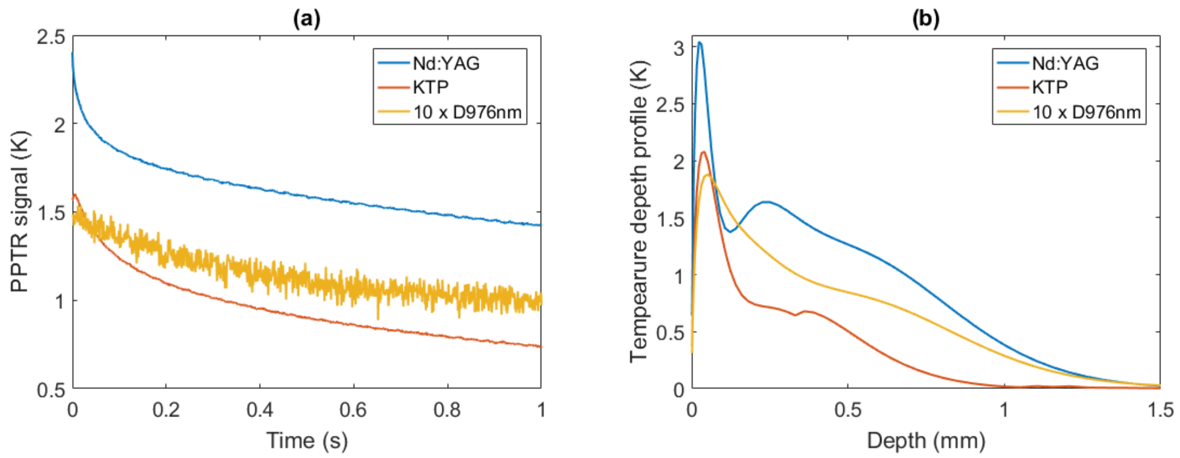

Figure 2: (a) PPTR signals recorded on the forearm of the volunteer 1 using the three lasers. (b) Corresponding reconstructions of the temperature depth profiles. The PPTR singnal and reconstructed profile of the diode laser were multiplied by 10 to ease comparison. Estimated exposure values were approx. 1.5, 0.4 and 0.05?? J/cm^2 for Nd:YAG, KTP, and diode lasers, respectively.

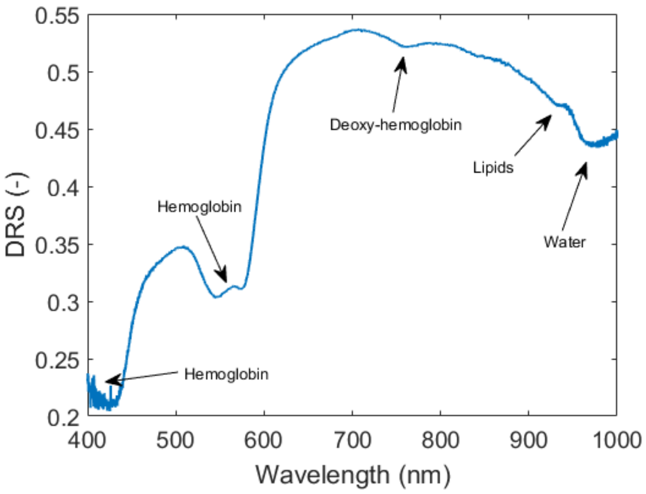

Figure 3: DRS recorded on the same spot as the above PPTR signals.

Description of the main results obtained:

- temperature profiles after irradiation of skin of 7 healthy volunteers using 4 different pulsed and cw lasers and their time evolution have been recorded; temperature depth profiles were reconstructed;
- DRS spectra were recorded and analyzed using inverse Monte Carlo;

Innovative knowledge resulting from COST networking through the Action. (Specific examples of Results vs. Objectives)

Significant scientific breakthroughs as part of the COST Action. (Specific examples)

The performed experimental investigations allow determination of temperature depth profiles and their comparison for 4 different laser wavelengths. Such broad studies for the same volunteers have never been done. The study result will provide additional knowledge about the light-tissue interaction and heat transport in human skin needed for better understanding laser therapy using the novel 940 nm and 970 nm diode lasers. The results will be widely published.

Tangible medium term socio-economic impacts achieved or expected. (Specific examples)

The knowledge of temperature depth profiles is crucial for developing new laser therapies and enable better choice of laser wavelengths for specific medical applications. It will offer the clinicians guidelines for performing laser therapies

Mutual benefits for the Home and Host institutions:
The Home and Host institutions have agreed that the common investigations will enable the increased knowledge in both institutions. The Szewalski Institute of Fluid-Flow Machinery Polish Academy of Sciences provided new laser sources to be used during the studies. Jozef Stefan Institute supported the investigations with their lasers, the knowledge of the PPTR technique, the DRS measurement and analysis.

Future collaboration with the Host institution (if applicable):
Future collaboration is planned in the field of medical laser application and diagnostics.

Foreseen journal publications or conference presentations expected to result from the STSM (if applicable):

The several journal publications including the one in Lasers in Surgery and Medicine and presentations at medical laser conferences are planned.

Conclusions

The knowledge of light-tissue interaction is of a great importance for understanding and optimizing both medical diagnostic and therapeutic procedures. The determined laser energy deposition maps for the two novel diode lasers determined in this study will guide the researchers and clinicians to introduce them into clinical practice, and compare their performance to the commonly used lasers (e.g., Nd:YAG). The main advantage of the diode lasers is reduced complexity, flexibility and lower price compared to the solid state lasers commonly used nowadays.

References

[1] Milanic, M.,Majaron, B., “Energy deposition profile in human skin upon irradiation with a 1,342 nm Nd:YAP laser,” Laser Surg Med*,* 45(1), 8-14 (2013).

[2] Naglic, P., Vidovic, L., Milanic, M., Randeberg, L. L.,Majaron, B., “Combining the diffusion approximation and Monte Carlo modeling in analysis of diffuse reflectance spectra from human skin,” Photonic Therapeutics and Diagnostics X*,* 8926, (2014).

STSM outcome form

Temperature depth profiling of human skin in-vivo using 532 nm, 970 nm, and 1064 nm lasers, Jozef Stefan Institute, February 14 – 20, 2017

STSM application number	**Home institution & country**	**Host institution & country**	**BM1205 WG**	**Objective of the collaboration**	**Results of the collaboration**
COST-STSM-BM1205-35950	The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Gdańsk Poland	Jozef Stefan Institute, Ljubljana (SI)	**WGX**	Temperature depth profiling of human skin in-vivo using 532 nm, 940 nm, 970 nm, and 1064 nm lasers.	Prof. Adam Cenian and the group at JSI performed the following measurements and analysis: (i) temperature profiles after irradiation of skin of 7 healthy volunteers using 4 different pulsed and cw lasers and their time evolution have been recorded; temperature depth profiles were reconstructed; (ii) DRS spectra were recorded and analyzed using inverse Monte Carlo;

I acknowledge that the described short-term scientific mission (STSM) was successfully carried out in the conditions here specified. Prospects of potential further collaborations on topics related to the spectroscopy and termography of human skin, and possible theapeutic applications of the studied lasers are expected in the coming months.

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