Abstract

Pulsed photothermal radiometry (PPTR) is an experimental technique based on photothermal effect, i.e., conversion of optical energy into heat. This technique can be used to measure optical and thermal properties of various materials. Theoretical explanation of physical phenomena behind PPTR was made quite accurately, allowing us to study homogenous and layered materials, such as human skin. Depth profiling, i.e., solving inverse problem to determine the laser-induced initial temperature profile from measured radiometric signal, became possible. As a result, some possible PPTR applications were introduced.
1 Introduction

In 1961, W. J. Parker introduced a new method of determining thermal properties of materials (thermal diffusivity, heat capacity and thermal conductivity) [1]. The method involves flashing a couple of millimeters thick specimen with high intensity light pulse and measuring temperature at the rear surface with a thermocouple.

The specimen is usually coated with a strongly absorbing layer so that all the light is absorbed at the front surface, resulting in a temperature jump, which is relaxed as heat diffuses toward the rear surface. From the shape of the temperature versus time curve at the rear surface (figure 1) thermal diffusivity $D$ in an adiabatic one-dimensional case can be determined by equation

$$D = 1.388 \frac{L^2}{\pi^2 t_{1/2}},$$

where $L$ is the sample thickness and $t_{1/2}$ is the time required for the rear surface to reach one half of the maximum temperature rise. In contrast to Parker’s method, which uses temperature sensors...
attached onto the solid surface, several non-contact techniques for measurement of thermal diffusivity were developed and were extensively reviewed in [2]. They are non-contact in both heating sample (e.g., with a pulsed laser beam) and in monitoring of thermal diffusion (using an optical probe). We will deal in this seminar with one of them, i.e., photothermal radiometry (PTR).

PTR relies on detecting infrared (IR) radiation from the sample which was excited by electromagnetic radiation. The main advantages of this method in comparison to the other photothermal methods are [3]:

• measurements can be made in vacuum, under high pressure, at low or high temperature and in other hostile environments,

• thermal properties can be measured much faster using IR detectors than conventional (non-optical) methods. Data can be gathered in a matter of micro or milliseconds depending on material properties and thickness. Consequently, time-dependent properties (e.g. during phase transitions) can be examined [4].

• not just thermal diffusivity, but also absorption coefficients and thickness of the sample can be obtained in a non-contact manner.

In a typical PTR measurement, IR emission is detected at the excitation spot in a backward direction ("single-ended" PTR) or on the opposite side of the excitation spot ("transmission" or "double-ended" PTR). The latter is often called "flash diffusivity" or "flash radiometry" technique in case of pulse excitation and was invented by Deem and Wood [5] just one year after Parker presented his method. Later, Tam et al. [6] developed single-ended pulsed PTR (PPTR) method and made possible measurements on samples, which cannot be accessed at the back surface. Another advantage of this method is its suitability for measuring absolute absorption coefficients in a range where transmission PPTR fails (absorption coefficient $\mu_a$ larger than $10^2$ cm$^{-2}$ or smaller than $10^{-2}$ cm$^{-2}$). However, limitations on the usefulness of PPTR occur for samples of low IR emissivity or low laser-damage thresholds [6].

2 Experimental setup

Although Parker carried out his pioneer experiments with a flash lamp [1], laser sources prevail nowadays. The choice of laser wavelength depends upon absorption properties of a sample, whereas the pulse duration is defined by thermal properties. If the laser pulse is short enough, heat cannot diffuse noticeably during excitation (pulse duration is much smaller than the typical diffusion time) and we can neglect the effect of pulse width [4]. A typical pulse duration therefore varies from a few nanoseconds in measurements of thin PVC films [4] to milliseconds when working with biological tissue [7], [8]. Energy delivered by the light pulse is limited with maximum sample heating in a range of 10°C to avoid sample damage or any non-linear radiometric effects (a radiometric signal is proportional to temperature rise only when it is much smaller than initial absolute temperature) [3].

The next step is to deliver the light to the sample. It is of great importance that laser beam, when reaching the sample surface, is uniform and collimated, so that temperature rise is homogenous in the lateral direction. Different groups use different techniques, but a very common one is to send light pulse from the laser to the optical fiber to homogenize the beam [9]. Then an objective is used to magnify image from the fiber to around 5 mm. The illumination spot should be large enough in comparison to the thickness of the sample or penetration depth, so that radial heat diffusion can be neglected. Incident angle according to the normal of the surface is usually very small (approx. 10°). To accomplish a normal incidence, a micro prism placed in front of an IR detector can be used as alternative to a microscope objective [8].

The emitted IR signal from central area of illuminated surface is collected by concave mirrors or lenses (both specially designed for IR light) and is detected with IR detectors. Cooling of a detector is often used to reduce a thermal noise. Filters can be placed in front of detector to eliminate the visible and near-IR radiation. Therefore, the detection bandwidth varies from $3 – 12\mu m$ [10], $8 – 12\mu m$ [4] to $3 – 5\mu m$ [7].

The detector system is calibrated using a blackbody source. For this purpose, the detector voltage is measured as a function of the temperature of a copper block coated with lampblack and heated
by a resistive heater [10]. This technique is nowadays replaced with dedicated computer-controlled blackbodies.

In figure 2 we can see an experimental setup that can be used in both single-ended backscattering mode and transmission mode. It uses very short (8 ns) pulses from a nitrogen laser. Gold-coated concave mirror collects blackbody emission which is then detected with a N₂ cooled HgCdTe IR detector. The signal from the detector goes through a fast preamplifier to the recording oscilloscope, triggered by a fast photodiode [4].

Figure 2: Experimental setup of Tam et al., appropriate for examination of thin samples. It can be used in single- or double-ended mode [4].

3 Theory

The following theoretical framework is based on the work of Leung and Tam [4]. If the excitation pulse is very short and detection system is fast enough, IR radiometric signal depends on the following material parameters: the absorption coefficients $\mu_a$ and $\mu_{IR}$ of the sample at the excitation and detection wavelengths, the thermal diffusivity $D$ of the sample and its thickness $L$ [4].

In order to determine the expression for blackbody emission from sample surface, we solve a one-dimensional heat diffusion model. An one-dimensional approximation can be made as long as the lateral dimension of uniformly illuminated area is much bigger than the characteristic length of the sample (i.e. sample thickness, light penetration depth $\mu_a^{-1}$). Temperature profile evolution inside the sample is described by diffusion equation

$$\frac{\partial^2 \Delta T(z,t)}{\partial z^2} - \frac{1}{D} \frac{\partial \Delta T(z,t)}{\partial t} = 0$$

where $D$ is thermal diffusivity of the homogenous sample (it doesn’t vary with depth) and $\Delta T(z,t) = T(z,t) - T_0$ is the temperature rise from initial temperature $T_0$. For now, we neglect heat loss due to convection and radiation at the sample surface ($z = 0$).

3.1 Semi-infinite sample

First, let us examine a homogenous non-scattering semi-infinite sample. This is often a good approximation if $\mu_a^{-1} \ll L$ and $\mu_s \ll \mu_a$, where $\mu_s$ is the scattering coefficient. A general solution satisfying
equation (2) can be derived with the use of Green’s function $G(z, z'; t)$ \[10\],\[12\]
\[
\Delta T(z, t) = \int_0^\infty \Delta T(z', 0) G(z, z'; t) dz'
\]
where Green’s function for adiabatic boundary condition and geometry of the problem (figure 3 with $L \to \infty$) using the method of images is
\[
G(z, z'; t) = \frac{1}{\sqrt{4\pi Dt}} \left[ \exp\left(-\frac{(z-z')^2}{4Dt}\right) + \exp\left(-\frac{(z+z')^2}{4Dt}\right) \right]
\]

Assuming normal light incidence, fluence distribution in a homogenous non-scattering absorber is described by Beer’s law \[10\]. If all absorbed light is converted to heat, the initial temperature rise is
\[
\Delta T(z, 0) = \frac{E_{inc} \mu_a}{\rho c} \exp(-\mu_a z)
\]
where $E_{inc}$ is the light fluence at the boundary reduced by any losses due to specular reflection from the surface, $\rho$ is sample density and $c$ is specific heat of the sample. Evaluating equation (3) for Green’s function (4) and initial temperature distribution (5), a solution $\Delta T(z, t)$ can be obtained.

A rough approximation of backscattered radiometric signal $\Delta S(t)$ at the IR detector is, according to Stefan’s law
\[
\Delta S(t) = K'\mu_{IR} \int_0^\infty \left[T^4(z, t) - T_0^4\right] \exp(-\mu_{IR} z) dz
\]
with $K' = C\varepsilon\sigma$, where $C$ is a factor due to detection properties, $\varepsilon$ is emissivity of the sample averaged over the detection spectral bandwidth, and $\sigma$ is Stefan-Boltzmann’s constant. Note that the radiation signal from different depths is weighted by a factor $\exp(-\mu_{IR} z)$. The temperature rise $\Delta T(z, t)$ is usually small compared to $T_0$ and so an approximation in first order of $\Delta T(z, t)$ can be made. Using this approximation and the time dependent temperature profile given by (3) we obtain radiometric signal
\[
\Delta S(t) = 4K\mu_{IR} \int_0^\infty \Delta T(z, t) \exp(-\mu_{IR} z) dz = \frac{E_{inc}}{\rho c} K' \frac{\mu_{IR} \mu_a}{\mu_{IR}^2 - \mu_a^2} \left[\mu_{IR} f(t/4\tau_a) - \mu_a f(t/4\tau_{IR})\right]
\]
where $K = 4K'T_0^4$, $f(x) = \exp(x)[1 - \text{erf}(x)]$ and $\tau_{a,IR} = (4\mu_{a,IR}^2 D)^{-1}$ are characteristic times, i.e., time required for the heat to diffuse over a distance $\mu_{a,IR}^{-1}$. For many nontransparent materials $\tau_{a,IR}$ are in range of $10^{-5} - 10^{-8}$s \[4\]. We can obtain the absorption coefficients by fitting experimental radiometric signal to theoretically predicted one, if thermal diffusivity of the sample is known.

Magnitude of the radiometric signal (7) depends on the product of absorption coefficients, $\mu_a\mu_{IR}$. Consequently, the signal vanishes for the samples that are transparent either at the excitation wavelength ($\mu_a = 0$) or at the IR detection wavelength ($\mu_{IR} = 0$).
3.2 Thin solid slab

PPTR is very useful for examining thermal properties of thin films where contact methods are inappropriate. In mathematical analysis of photothermal radiation of a thin solid slab, the procedure is the same as in the previous chapter. When solving equation (2), we add another adiabatic boundary condition at the rear surface. If the initial temperature rise \( \Delta T(z,0) \) is given, then the temperature at a later time is given by (12)

\[
\Delta T(z,t) = \frac{1}{L} \int_0^L \Delta T(z,0) \, dz + \frac{2}{L} \sum_{n=1}^{\infty} \exp(-\frac{n^2\pi^2}{L^2}Dt) \times \cos\left(\frac{n\pi z}{L}\right) \int_0^L T(z',0) \cos\left(\frac{n\pi z'}{L}\right) \, dz'
\]

(8)

For the initial temperature rise given by (5), time decay of radiometric signal is plotted in figure 4a. Its analytical form can be easily calculated using equation (6). Time evolution of the signal can be separated into two limiting cases in addition to typical time \( \tau_L \) needed for heat to diffuse over distance \( L \)

\[
\tau_L = \frac{L^2}{\pi^2 D}
\]

(9)

For times \( t \ll \tau_L \) initial temperature rise relaxes in the same way as in the semi infinite case. Consequently, the irradiance signal depends only on \( \mu_a, \mu_{IR} \) and \( D \). On the other hand, for times \( t \gg \tau_L \) relevant length scale is \( L \) and not \( \mu_a^{-1} \) or \( \mu_{IR}^{-1} \). On figure 4 these properties are presented. Theoretical profiles of signal for early times are insensitive to sample thickness (figure 4a) and for later times the signal is quite independent of the absorption coefficients (figure 4b). This allows us to determine all the three parameters (\( \mu_a, \mu_{IR} \) and \( D \)) from one signal. By fitting experimental data with a theoretically predicted signal \( \Delta S_L(t) \) for \( t \ll \tau_L \), we can get \( \mu_a \) and \( \mu_{IR} \), if thermal diffusivity \( D \) is known. The latter can be found by fitting the data at \( t \gg \tau_L \).

Figure 4: (4a) Radiometric signals from front surface for a semi-infinite solid and a slab of thickness \( L \) are almost the same for \( t < \tau_D \). However, thickness plays a significant role for later times. (4b) Thickness \( L \) is now the same for both curves, but absorption coefficients (here presented in terms of characteristic diffusion times) differ by a factor of 4. In that case, signals are the same for later times but differ for \( t < \tau_D \).

3.3 Layered structures

Another very useful application of PPTR is studying properties of layer structured samples. The depth of an absorber can be determined from PPTR signal. Subsurface absorbers significantly alter the sam-
ple’s optical properties and consequently also the initial temperature profile. In this simple model, the following assumptions were made [13]: Sample consists of a uniform, semi-infinite substrate with absorption coefficient $\mu_2$ and above-lying absorbing layer of thickness $d$ and absorption coefficient $\mu_1 < \mu_2$. Thermal diffusivity of both layers is the same and there is no thermal resistance at the interface. The initial temperature distribution is therefore given by

$$\Delta T(z,0) = \begin{cases} T_s e^{-\mu_1 x} & 0 < x < d \\ T_s e^{-\mu_1 d} e^{-\mu_2 (x-d)} & x > d \end{cases}$$

(10)

Because we assumed thermal homogeneity, the temperature rise $\Delta T(z,t)$ can be calculated using the Green’s function [4]. The measured IR signal is obtained using the procedure described in chapter 3.1. Because the heat flow from the subsurface absorber (layer 2) needs some time to reach the surface, a maximum in PPTR signal is observed. The time when the peak occurs is strongly dependent upon the thickness $d$, whereas the influence of absorption in both layers can be neglected [13]. Therefore, the thickness $d$, which is equal to the depth of a substrate, can be deduced from the time delay between laser pulse and peak of the PPTR signal.

An alternative approach to study optically layered samples such as human skin was given by Milner et al. [11] and Prahl et al. [14]. Their goal was to convert the detected PPTR signal to an initial temperature distribution $T(z,0)$ without a priori knowledge of the location or the strength of the absorbers [14]. The principle of their method is described in next chapter.

4 Depth profiling

More accurate description of physical processes is needed for following approach. Therefore, we must add more accurate assumptions governing boundary conditions and wavelength dependence of some parameters. In the following analysis [7], we assume a semi-infinite slab with a constant thermal diffusivity at all depths. A radiometric signal is not representative of surface temperature, but rather a sum of attenuated contributions from all depths. Instead of Stefan’s law, we use Planck’s law of radiation to describe the locally emitted power density at wavelength $\lambda$:

$$B(\lambda, T) = \frac{2\pi hc^2}{\lambda^5 (\exp(hc/\lambda k_b T) - 1)} \approx B(T_0) + B'(T_0) \Delta T$$

(11)

Again, we take temperature rise $\Delta T$ to be much smaller than absolute initial temperature $T_0$ to linearize equation (11). Therefore, equation (6) for dynamic part of the radiometric signal is rewritten [7]

$$\Delta S(t) = CB'(T_0) \mu_{IR} \int_0^\infty \Delta T(z,t) \exp(-\mu_{IR} z) dz$$

(12)

where constant $C$ accounts for properties of the experimental setup.

4.1 Boundary condition

Contrary to the boundary condition in former examples, we now take into account convective and radiative losses at the air-material interface [11]. Because no mass is associated with interface, no capacity is available for storing energy. Therefore, conservation of energy states that the flow into the interface must equal the flow out of interface [15]. Boundary condition is given by

$$k \frac{\partial \Delta T}{\partial z} - H_r \Delta T - H_{conv} \Delta T = 0 \quad \text{at } z = 0 \quad \text{or} \quad \frac{\partial \Delta T}{\partial z} = h \Delta T$$

(13)

where $k$ is thermal conductivity of a sample, $H_r$ is coefficient of radiative surface heat transfer [12] and $H_{conv}$ is convective heat transfer coefficient. $h = (H_r + H_{conv})/k$ is reduced heat transfer coefficient with a typical value $h = 0.02 \text{mm}^{-1}$ for skin [7]. The limiting cases of $h = 0$ or $h = \infty$ correspond to perfectly insulated and constant-temperature surface, respectively.
4.2 Wavelength dependence of $\mu_{IR}$

In the most PPTR studies, wavelength dependence of parameters is neglected. Nevertheless, Majaron et al. [7] showed that taking into account wavelength dependence of IR absorption coefficient $\mu_{IR}(\lambda)$, blackbody radiation $B(\lambda, T)$ and spectral sensitivity of detector $D(\lambda)$, all presented in figure 5, significantly improves the accuracy of reconstructed temperature profile [16]. The equation for radiometric signal should therefore be integrated over the detection band ($\lambda_l$ and $\lambda_h$)

$$\Delta S(t) = C' \int_{\lambda_l}^{\lambda_h} D(\lambda) B'(T_0, \lambda) \mu_{IR}(\lambda) \int_0^\infty \int_0^\infty \Delta T(z', 0) G_b(z, z'; t) \exp(-\mu_{IR}(\lambda)z) dz dz' d\lambda$$

where $G_b(z, z'; t)$ is the Green’s function, corresponding to the new boundary condition [11]. A calibration of the system (blackbody radiometric signal is compared with (11) for different temperatures) eliminates any detection specific parameters so that absolute measurement of temperature rise is possible [16].

\[\begin{array}{c}
\text{(a)} \\
\mu_{IR} \quad \text{[mm}^{-1}] \\
\hline
\text{(b)} \\
\text{InSb} \\
\text{HgCdTe} \\
B'(T, \lambda) \quad \text{[arb. units]} \\
\text{Wavelength [\mu m]} \\
\end{array}\]

Figure 5: Wavelength dependence of IR absorption coefficient (upper graph), blackbody radiation - temperature derivative of blackbody emitted light power density $B'(\lambda, T)$ and spectral sensitivity of IR detectors [17]

4.3 Reconstruction

Because none of the elements in the equation (14) vary with initial temperature rise $\Delta T(z', 0)$, we can perform integration over $z$ and $\lambda$ in kernel function $K_\lambda(z', t)$, so that radiation signal can be written as a simple convolution [18]

$$\Delta S(t) = \int_0^\infty K_\lambda(z', t) \Delta T(z', 0) dz'$$

In practice, measured radiometric signal is discretized and is represented as a vector $\Delta S = \Delta S(t_i)$. Similarly, reconstructed initial temperature profile is written in a form of a vector $\Delta T = \Delta T(z_j)$ and is connected with a signal through multiplication with a kernel matrix $K = K(t_i, z_j)\Delta z$.

$$\Delta S = K\Delta T$$

Properties of discretization are uniformly spaced $t_i$ ($i \in [1, N_t]$) and $z_j$ ($j \in [1, N_z]$) and $N_t \geq N_z$ so that the problem is overdetermined [11].

The initial temperature profile is obtained by solving an inverse problem, which is a difficult problem in practice. The main reasons are ill-determined rank of matrix $K$, preventing calculation of its inverse,
and noise present in experimental signals [18]. One of the methods for computation of initial temperature distribution is to select $\Delta T$ that minimizes the Euclidean norm of the residual vector $||r|| = ||\Delta S - K\Delta T||$. 

$$(17)$$

5 Applications

PPTR was applied to nondestructive evaluation of subsurface thermal properties. Thermal diffusivities of numerous materials, including molten salts, Teflon films and diamond films were measured [2]. In fact, the "laser flash analysis" (name for transmission PPTR in material testing community) is a standard method for determining thermal properties of homogenous materials, especially useful in extreme conditions and for examining dangerous materials. For example, Deem and Wood measured thermal diffusivity of nuclear reactor fuel materials at high temperatures. Nowadays, commercial products for "laser flash analysis method" exist [10].

When thermal properties of a sample are known, PPTR can be used to determine absorption and scattering coefficients [10] of biological samples. Long et al. [13] showed that PPTR can be used to characterize optically layered structures. With the use of a simple 2-layered model (chapter 3.3), they analysed depth of subsurface blood layers in human skin. Relatively simple geometries and analytical treatment of light transport in the sample are common to all these works. However, some knowledge about number of layers or their depth is needed to perform the analysis [14].

5.1 Temperature depth profiling

PPTR temperature profiling was intensively investigated by many researchers (see references in [18]) with the goal to develop non-invasive method for determination of subsurface chromophore distribution in biological tissue.

In comparison to the other imaging techniques, PPTR provides structural information and absolute temperature rise at once. This makes it a very powerful tool in medical laser applications (e.g. treatment of port wine stain-PWS), where photothermal effect is used for therapy purpose [8]. Because skin properties vary significantly from patient to patient, parameters of laser treatment should be selected individually. PPTR depth profiling can be used to determine individual maximum safe radiant exposure directly by monitoring temperature increase in response to a diagnostic subtherapeutic laser pulse [20], [21]. A structure of blood lesions and their response to laser irradiation were successfully monitored. Next, laser tattoo removal treatment was quantitatively characterized [22].

Broadening and attenuation of distinct temperature peaks that increase with object depth, limit PPTR temperature profiling to depths less than 1 mm. The PPTR temperature profiling accuracy and axial resolution were determined on agar tissue phantoms with thin absorbing layers [18]. Using an optimized experimental setup and spectrally composite kernel matrix in the reconstruction process, the depths of absorbing layers were determined and compared to data obtained by high resolution magnetic

![Figure 6](image)

Figure 6: (a) Average temperature profiles reconstructed from ten PPTR signals from agar tissue phantoms with thin absorbing layers. (b) MRI cross-sectional image of the samples [18].
resonance imaging (figure 6). The widths of reconstructed temperature peaks reach 14–17% of their depth, significantly less than in earlier reports on PPTR depth profiling in water-based tissues [18].

5.1.1 Bruise age determination

Determination of the age of traumatic bruises is an open problem in forensic medicine. Subjective visual inspection or inspection of photos of bruises is not sufficiently accurate. Several factors as the depth of the spilled blood, natural skin tone, ambient light conditions, etc., prevents an accurate and reliable determination of the time of injury [23]. A simple model of hemoglobin mass diffusion and biochemical transformation kinetics was introduced to describe the healing process [23]. Hemoglobin from ruptured blood vessels diffuses into dermis and is converted to biliverdin and removed with lymphatic system drainage. Concentration of hemoglobin $N_h$ is described by diffusion equation

$$\frac{\partial N_h}{\partial t} = D_h \nabla^2 N_h - \frac{N_h}{\tau_h} \tag{18}$$

with hemoglobin mass diffusion constant $D_h$ and hemoglobin degradation time $\tau_h$. Comparing PPTR measurement and simulated PPTR measurement one can monitor hemoglobin diffusion and degradation quite accurately. Procedure is the following [23]: Optical properties of skin model with multilayered dermis are calculated (taking into account calculated time-dependent hemoglobin distribution). Laser

![Figure 7: Time sequence of the bruise healing process.](image)

(a) Digital photographs. (b) Laser-induced temperature profiles as reconstructed from PPTR measurement and simulated profiles 44 hours, 68 hours, 90 hours, 113 hours, and 210 after injury. (c) Corresponding extravasated hemoglobin depth distribution calculated using [18] [23].
energy deposition profile and temperature rise in each layer is determined using a Monte Carlo simulation. The established temperature profile $\Delta T(z,0)$ is developed in time via heat diffusion. The PPTR radiometric signal is simulated. Initial temperature distribution is reconstructed from the latter using the same reconstruction algorithm as for the measured PPTR signals. When parameters in simulation (source time $T$ that represents the bruise severity and hemoglobin mass diffusivity $D_h$) are optimized in a way that reconstructed temperature profiles (simulated and measured) match as good as possible, the hemoglobin concentration used in simulation presents the hemoglobin distribution in skin.

Estimates of the hemoglobin mass diffusivity ($D_h = 0.0006 \text{m}^2/\text{s}$), hemoglobin degradation time, as well as approximate skin geometry can be obtained. The results (figure 7) show that PPTR depth profiling is a viable technique for quantitative characterization of the bruise healing process [23].

5.1.2 Photothermal tomography

In 1999, Telenkov et al. presented their photothermal imaging technique [8]. The signal was remotely collected after pulsed laser exposure using a fast IR camera. They developed a tomographic reconstruction algorithm to process IR images and compute the initial 3D temperature increase in tissue. The method was used to monitor 3D temperature increase in PWS blood vessels immediately following the pulsed laser exposure (figure 8) and showed that temperature rise of blood may exceed 60°C at 60 mJ/mm². Such a combined imaging method with temperature monitoring may be useful in optimization of laser dosimetry required for irreversible destruction of targeted blood vessels throughout an extended treatment protocol [8]. Their work was later improved by Choi et al. using a dual-wavelength excitation technique [24].

![Figure 8: 3-D isosurface rendering of a photothermal tomography image obtained from in vivo human PWS skin [24].](image)

6 Conclusion

Pulsed photothermal radiometry was presented in a manner of its “historical development”. From Parker’s idea to measure thermal properties of materials using flash light excitation, upgraded by Deen and Wood that replaced thermocouples with non-contact measurement of temperature by detecting IR radiation at backside of the sample, to Tam and Sullivan’s idea, who converted PPTR into “single-ended” method conventional for remote sensing. Basic components of experimental setup were explained briefly. Theoretical background of PPTR for homogenous semi-infinite solid, thick solid slab and layered sample was explained as well as for more advanced approach, called depth profiling. Our interest in biological samples is the reason why many other very important (nonbiological) applications of PPTR, e.g. measuring of thermal diffusivity with laser flash method, were not reviewed so intense in this seminar. We showed how theoretical model (boundary condition, wavelength dependence of $\mu_{IR}$) was improved and presented some of possible PPTR applications.
References