Application of the front detection photopiroelectric configuration to the study of in vivo human skin

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**Abstract.** We report a novel method for measurements in vivo of the penetration of topically applied substances by inverse photopyroelectric configuration. This configuration was used to obtain the thermal effusivity, as a function of time, of in vivo human skin with ointments. This thermal magnitude was employed to characterize the penetration on the anterior-face of the volunteers forearm. This thermal effusivity was fitted with an exponential function in order to obtain a parameter (characteristic time) for the penetration. The substances used were a sunscreen and Vick Vaporub ointment. We found that the sunscreen have a characteristic time bigger that the Vick Vaporub ointment. The feasibility of skin hydration studies are discussed.

1. INTRODUCTION

In the evaluation and characterization of materials, a wide variety of physical properties are considered. Among them are the thermal properties, which can be studied with photothermal techniques (PT) [1, 2]. These techniques has been demonstrated to be an useful tool for thermal characterization. In particular, the inverse photopyroelectric (IPPE) configuration [3] is a well know photothermal method, used to measure thermal properties of different kind of materials, in which light impinges directly on one surface of the pyroelectric transducer and the sample is in contact with the other surface. This method does not involves direct illumination of the sample, and only the thermal evolution of the system is monitored. All these characteristics make the IPPE very appropriate in the study of photosensitive systems when it is desired to avoid the light, such as in some studies of the human skin.

In this work, we present preliminary results of measurements in vivo of penetration of topically applied substances by IPPE configuration. The IPPE amplitude was detected as a function of time and it was analyzed with a one dimensional heat diffusion model in order to obtain the thermal effusivity (\(\epsilon\)). The purpose of this study was to demonstrate the feasibility of using a non-invasive measurement, such as the thermal effusivity, provided by IPPE configuration, for dermatology research, in particular for in vivo human skin penetration measurements of topically applied substances and skin hydration.

2. THEORETICAL CONCERNS

It has been shown that the amplitude of the IPPE signal [3], is given by

\[
|U| = \frac{f^{1/2}}{\epsilon_a + \epsilon_b} B,
\]

where \(f\) is the modulation frequency of the incident laser beam, \(i = a\) and \(b\) for air and backing, respectively; and \(B\) is given by

\[
B = \frac{\pi^{1/2} pl \omega_0}{2\epsilon},
\]
here \( p \) and \( l_p \) are the pyroelectric coefficient and thickness of the transducer respectively, \( I_0 \) is the intensity of the radiation, and \( \varepsilon \) the dielectric constant of the sensor.

If the amplitude of IPPE signal is measured for a substance whose thermal effusivity is well-known, then the Eq. (1) can be rewritten as follows

\[
|U| = \frac{e_a + e_{ref}}{e_a + e_b} |U_{ref}|,
\]

where the subindex \( \text{ref} \) is about the well-known substance. From Eq. (2), the thermal effusivity of the substance, which is in contact with the pyroelectric sensor, is given by

\[
e_b = (e_a + e_{\text{ref}}) \frac{|U_{\text{ref}}|}{|U|} - e_a.
\]

Water was used as a reference substance.

3. EXPERIMENTAL CONCERN

The IPPE cell was in contact with the outer skin surface of the forearm volunteers. The experimental consists of an infrared diode laser operating at 1 mW. The laser beam was sinusoidal modulated with a driver at 5 Hz, and it was sent onto the pyroelectric transducer. The lock-in amplifier was interfaced with a personal computer, which recorded the amplitude of the IPPE signal as a function of time.

A group of five volunteer, from 20 to 30 years old were selected for the study of topical application by means of IPPE technique. These subjects fulfilled the following inclusion criteria at the moment of the experiment: to be healthy, not be allergic to any topical drugs using in this study, not be exposed to solar radiation in the last two hours and without antecedents of skin diseases or pathologies at skin. The substances used in this experiments were a sunscreen (with a solar protection factor of 45) and a Mexican commercial ointment (Vick-Vaporub). The recordings consisted of several sessions of measurements.

In order to explore the feasibility of skin hydration, the IPPE amplitude as a function of frequency was obtain for water, skin, and wet skin. To obtain wet skin, it was exogenously hydrated by prolonged immersion in water (about 15 minutes) until wrinkled. Measurements were then performed immediately.

Figure 1. (a) IPPE amplitude and (b) thermal effusivity as a function of time, for the sunscreen applied on the skin of the anterior-face of the volunteers forearm.

Figure 2. IPPE amplitude as a function of frequency, for the air (A), dry skin (S), wet skin (WS) and water (W).

Figure 1(a) shows the IPPE amplitude as a function of time for the sunscreen topically applied. As it can be seen, the amplitude initially decreases until a constant level is achieved. To explain this
changes in IPPE amplitude, we remember that the photopyroelectric signal is proportional to the average temperature $ac \bar{T_{ac}}$ of the sensor. A change of the pyroelectric signal on the time is due to a change of $\bar{T_{ac}}$ on the time. A decrease in $\bar{T_{ac}}$ can be due to many factors, one of them is the lost heat in it when it was put in contact with a sink. In our experiments, the heat sink is the skin with topically applied substance. On the other hand, when a substance of topical application penetrates the stratum corneum, and reach the epidermis, the conduits of epidermis are filled until the saturation; as a result the penetration is slower than at the beginning. This is the heat sink that changes in the time.

Thermal effusivity was estimated using Eq. (3), see Figure 1.a. To obtain a penetration parameter, the thermal effusivity was fitted to

$$e(t) = \epsilon_1 + \epsilon_2[1 - \exp(-t/\tau)]$$

where $\epsilon_1$ is the point where it initiates the curve, $\epsilon_2$ is the height of the curve, and $\tau$ is the time constant, which we suppose that is the time in which the penetration activity diminishes to 1/e of the initial activity. We obtain that, $\tau$ is 946 s and 323 s for the sunscreen and Vick Vaporub, respectively.

In Figure 2, the IPPE amplitude as a function of frequency for water, skin, and wet skin are shown. As it can be seen, dry and wet skin can be differentiate through the IPPE amplitude.

Acknowledgements
The authors thanks to Juan Carlos Martínez and Juan Manuel Noriega for technical supports. This work was partially supported by CONACyT (Project no. 38749-E) and by CONCyTEG (Project no. 03-K117-029).

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