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NON-PERTURBED PHOTOLUMINESCENT THERMOMETRY (PLT) SUITABLE FOR MICROWAVE HYPERTHERMIA IN CANCER PATIENTS

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SUMMARY

A new concept of Photoluminescent Thermometry (PLT) for non-perturbing measurement of temperature in the presence of electromagnetic fields is presented. PL spectroscopic studies demonstrate CaS(Eu,Sn) phosphors to have optimum properties for a hyperthermia probe. Several PLT probes have been constructed and tested to demonstrate that real-time temperature as measured with these probes remain unperturbed in microwave fields at power densities > 325 mW/cm2. Temperature resolution of 0.1 degree C has been achieved in the range of 37-47 degrees C and the calibration stability over periods of months is found excellent for use invivo during hyperthermia treatment.

The PLT system is found particularly suitable for real-time SAR measurements in liquid phanta. Such SAR measurements in a standard phantom material can be used to compare microwave applicator characteristics and influence of differing coupling geometries.

A simple, inexpensive photoluminescent photographic (PLP) technique is shown to be a feasible alternative to produce 2D temperature maps in phantoms. So far, invitro thermal distributions have been recorded by other authors using expensive infrared thermographic cameras. The PLP technique, with some refinements, shows high potential for becoming a suitable, inexpensive quality control method in the clinic and a standard technique to review hyperthermia treatment parameters in multiple institution trials.

INTRODUCTION

In recent years several innovative methods have been reported for non-perturbed or minimally perturbed measurements of temperature in the presence of strong EM fields (1-7). Ideally, for application in humans during hyperthermia treatments of cancer, temperature probes should be less than 1mm in size and yet be structurally strong for tissue implantation. In addition, they should have stable calibration and temperature resolution of about 0.1 degree C and dielectric properties suitable to measure unperturbed tissue temperatures.

We have used the temperature dependent photoluminescent properties of some non-conducting materials coupled with minimally perturbing glass or plastic optic fibres to develop a Non Perturbing Photoluminescent Thermometry (PLT) System (Samulski & Shrivastava 1980). Our approach inherently differs from the Luxtron Fluroptic Probe described by Wickersheim & Alves 1982. They measure temperature based on luminescent intensities which, in addition to probe temperature, depend on a number of extrinsic factors, whereas we have used intrinsic time dependent properties of the sensitive element. Our approach has two potential advantages: first, it can have intrinsically calibrated long term stability with interchangeable probes and second, the less stringent optical coupling requirements allow simpler fabrication.

Characteristics of PL Thermometry and potential applications are presented below.

PHOTOLUMINESCENT THERMOMETRY (PLT)

A schematic design of the basic PLT system is shown in Figure 1.

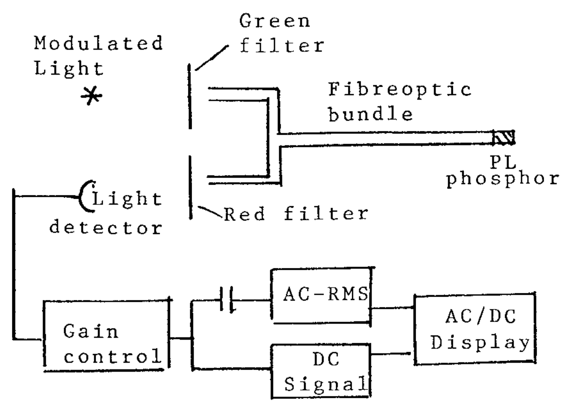

Figure 1. Schematics of PLT Probe

PL spectroscopic studies demonstrate Europium and tin activated calcium sulphide (CaS:Eu,Sn) to have optimum properties for a hyperthermia probe (Samulski:et al 1982). Its PL emission is peaked at 640 nm. with a transient response showing a sharp initial peak with a short lifetime (~50 μs) and a persistent tail with a long lifetime (>10 ms). The relative probabilities for transition via the fast and slow pathways are temperature dependent. We have differentiated the probabilities of slow and fast response by modulating the excitation signal at a suitable frequency.

We find that at excitation frequency of about 1 kHz, the fast PL response separates nicely into an oscillating (AC) signal superposed on a constant (DC) signal accumulated by the slow PL response. The temperature dependence of the ratio of the AC to the DC signals is shown in figure 2. The coinciding data for three probes differing in diameter, length, optical response and other extrinsic factors clearly demonstrates the stable, intrinsic, interchangeable calibration of this system.

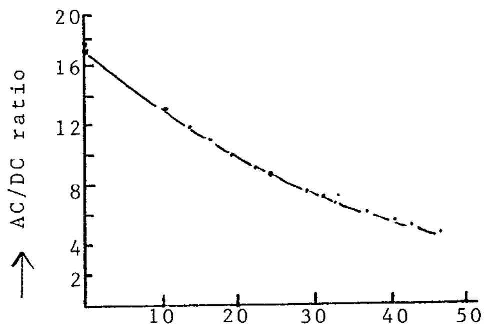

Figure 2. Identical calibration curves for 3 probes differing in diameter length and optical response.

Several PLT probes less than 1 mm in diameter have been constructed and tested to demonstrate that real-time temperatures measured with these probes remain non-perturbed in microwave fields at power densities > 325 mW/cm2 (figure 3). Temperature resolution of 0.1 degree C has been achieved in the 37-47 degree C range and the calibration stability over periods of months is found acceptable for use in hyperthermia patients.

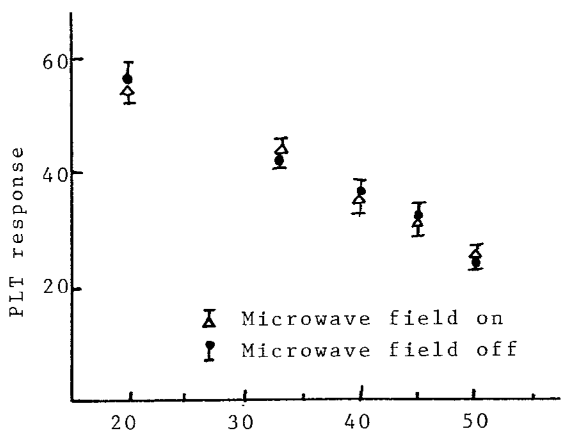

Figure 3. Unperturbed PLT response with microwaves on or off.

The PLT probe is found to be particularly suitable for real-time SAR measurements of Specific Absorption Rate (SAR) in liquid phanta. We believe this is a suitable approach to characterize hyperthermia applicators. We have used a prototype phantom using saline-alcohol muscle equivalent dielectric mixture behind a 1cm fat interface for SAR measurements equivalent to those made in gel phanta using the thermographic camera. Figure 4 shows an SAR profile measured with the PLT in this phantom. Comparisons with SAR measured in Guy gel phantom with Bowman probes or a thermal camera are planned. The liquid phantom together with the PLT system can provide a practical transportable system for review of applicator characteristics in multiple institution clinical hyperthermia trials. Also, it is suitable for simulation and studies of specific applications and clinical geometries.

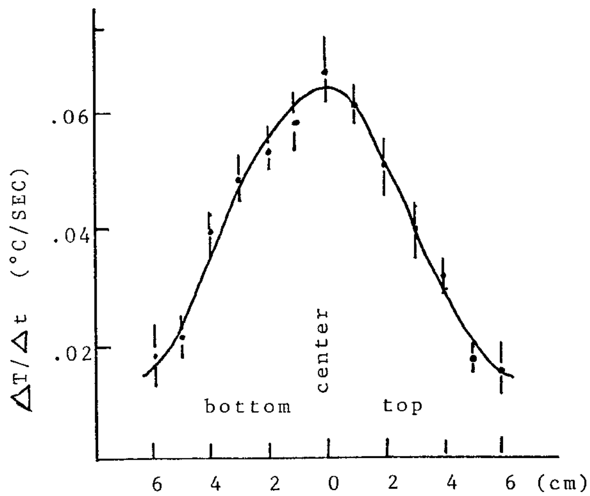

Figure 4. Relative SAR data in liquid phantom (80% saline, 20% ethanol). Dual Ridge Applicator (net power 93 watts; freq. 775 MHz)

PHOTOLUMINESCENT PHOTOGRAPHY (PLP) FOR THERMAL MAPPING

We have also explored the possible use of photoluminescence (PL) properties for 2D thermal mapping. In a simple single trap first order model, the PL intensity at time t from a phosphor at temperature T is given by

$$I(t,T) = \frac{N_0}{\tau_0} e^{-t/\tau_0} \left[1 + \frac{\epsilon}{kT_0^2} (T - T_0) \right]$$

Where No= traps filled at t=o, τ_0 is the decay time for a trap at energy ϵ and at phosphor temperature To. k is the Boltzmann's constant. Thus, if a phosphor is uniformly spread a uniform excitation and a fixed timing sequence is used, one can, in principle, correlate after glow intensity to changes in phosphor temperature over a narrow range. Although PL kinetics of most materials are not as simple and decay not first order as in the above equation, we have tried a photoluminescence photograph (PLP) technique to image 2D thermal distributions with moderate success.

Figure 5 shows the increase in photographic density versus temperature in the 35-45 degrees C range on a phantom surface uniformally doped with ZnS:Cu phosphor. This material gives a sufficiently long and bright after glow for photographic recordings of emission intensity. Photograph was taken 30 seconds after extinguishing a UV excitation lamp. A thermocouple was used to verify the temperature gradient and background film density was subtracted from the signal.

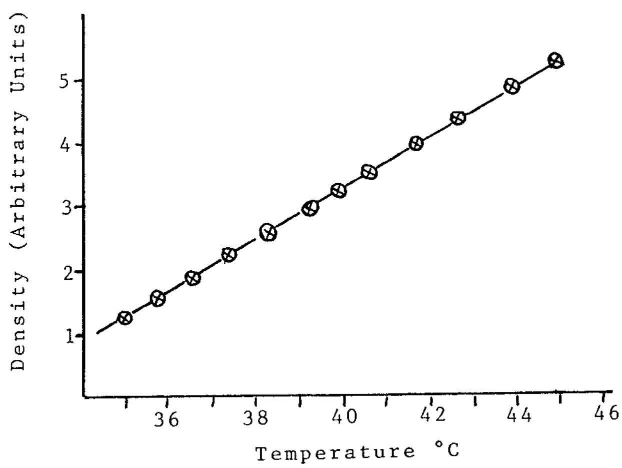

Figure 5. Photographic density vs phosphor temperature.

Figure 6 is a PLP thermal map on a muscle equivalent Guy gel phantom surface after 3 minutes of heating with a ridged wave guide applicator at 680MHz and 50 watts forward power. A comparison with thermocouple measurements in a linear dimension are well within 1 degree C. The time lag between PLP and thermocouple measurements was about 60 seconds. Spatial resolution was about 2mm (limited by film magnification and aperture of density scanner) and temperature resolution was about 0.4 degree C limited by film density noise. These results are better than we expected. Although greater accuracy will require more stringent control of many variables during construction, heating and photographing of the phantom, figure 6 does demonstrate the feasibility of the PLP concept.

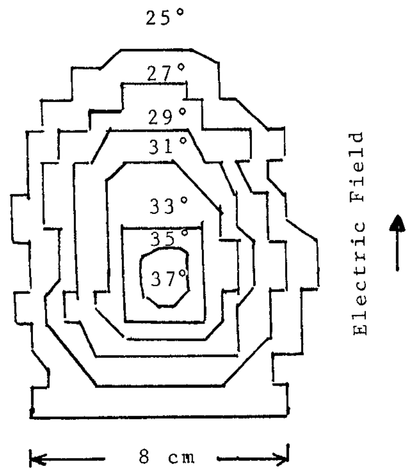

Figure 6. A 2D thermal map obtained with PLP technique.

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