Journal of Thermal Analysis and Calorimetry, Vol. 76 (2004) 949–954

DETERMINATION OF RADIATION POWER OF THE SOLAR-SIMULATED LIGHT SOURCE

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(Received October 1, 2003; in revised form November 27, 2003)

Abstract

Calorimetric method for the determination of radiation power of the solar-simulated light sources has been proposed. The application of the differential scanning calorimetry guarantees very high sensitivity (1 μW) of the measuring property, independent of the wavelength (within 300–1200 nm). The applied method yields reliable calibration curves of the radiation power *vs*. wavelength with good accuracy.

Keywords: microcalorimetry, radiation power, solar-simulated light source

Introduction

Solar-simulated light sources such as xenon, tungsten or mercury lamps are commonly used in photoelectrochemical studies [1–3]. The main issue in such studies is the efficiency of the solar energy conversion into either electrical or chemical energy. The knowledge of the radiation power incident on the surface of a photoelectrode is essential to the determination of this efficiency. Also, the dependence of the radiation power *vs*. wavelength is needed to study solar energy conversion parameters such as incident photon-to-current conversion efficiency, IPCE [4]. There are several measurement methods of the radiation power based on the determination of the effect of the incident light radiation on the following surface properties such as a change of the surface temperature, evaporation, change of colour, fluorescence, emission of electrons etc. [5–8]. However, all mentioned methods suffer from either limited wavelength range of validity or difficulties in using them in photoelectrochemical conditions. The calorimetric technique remains spread method [9–11]. It seems to be very promising as a direct method allowing determination of the radiation power over a wide range of wavelengths [12]. A high sensitivity instrument (within 0.1–200 mW range of the power) is essential for such purposes. In this paper we describe a method determining the radiation power of the artificial solar simulated light source using differential scanning calorimetry (DSC) in particular on photoelectrochemical cells (PEC) for water photoelectrolysis.

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1388–6150/2004/ $ 20.00

Akadémiai Kiadó, Budapest
Kluwer Academic Publishers, Dordrecht

Principle of DSC method

The idea of radiation power determination by means of calorimetry is very simple. The energy of light is completely absorbed by a black body and then converted into integral energy (heat) of the black body which is measured by calorimetry. The DSC method determines the difference of heat flux (heat power) transported to both the specimen and the reference, under the influence of some external impulses such as gradients of temperature, pressure, electrical potential or light.

Experimental

DSC equipment

The standard DSC equipment (2010 TA Instruments) was modified in order to determine of the radiation power. Platinum black was chosen as a light absorber because it shows practically complete light absorption within wide range of wavelengths (95–97% up to 9 μm [13, 14]). The standard containers (for the studied specimen and reference) were replaced by Pt containers covered by Pt black. The technique of Pt black deposition is described elsewhere [15]. A brass lid with a quartz window was constructed instead of the standard Ag lid. The measuring system is shown schematically in Fig. 1.

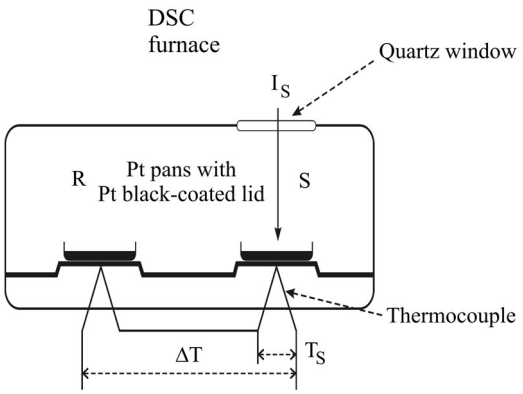

Fig. 1 Schematic design of the measuring system

DSC calibration

The monitoring signal of the DSC is a temperature difference, ΔT, between the studied, T_S, and reference, T_R, specimens (ΔT=T_S–T_R). This difference assumes a zero value (ΔT=0) for linear heating of the furnace if both specimens are ideally symmetrical (both samples have the same geometry and heat capacity). The incident flux of the electromagnetic waves on the studied specimen disturbs this dynamic quasi-equilibrium and it results in a non-zero ΔT measuring signal which is related to:

$$\Phi_S - \Phi_R = \Phi_m = \alpha \Delta T \quad (1)$$

where Φ_S and Φ_R are the heat fluxes to the studied and reference specimens, respectively; α is a constant which should be determined by calibration procedure. Some standard specimens are used for calibration. Both temperature and heat of the phase transition of the standard used served to determine of the real temperature of the specimen and the parameter α. Indium was used as a standard in our investigations. Figure 2 illustrates DSC response in such case. The heat required for melting of the used indium specimen, Q_m, can be determined from the following relation:

$$Q_m = \int_i^f \Phi_m(t)\mathrm{d}t \quad (2)$$

where t is time, i and f denote the initial and final stage of the experiment. The real temperature of the specimen can be determined from the extreme value of the DSC signal.

The determined heat of melting was found Q_m=28.61 J g^{-1}. This value is very close to 28.42 J g^{-1} provided by TA Instruments. Also the experimental melting temperature T_m=156.5±0.1°C well agrees with the reference data (156.60°C) [16].

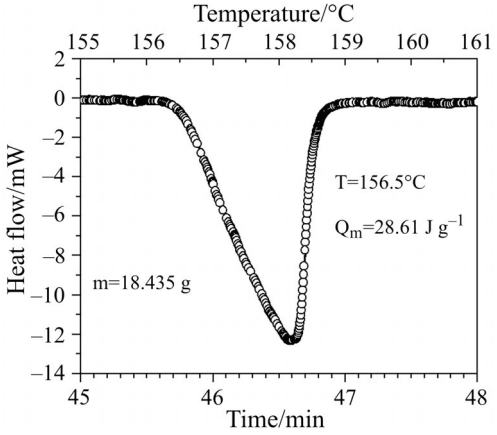

Fig. 2 Heat flow *vs.* time. Calibration curve of the DSC equipment

Measurements

The optical system consists of the light source (lamp Xe 450 W), grating monochromator Triax 180 Jobin Yvon and optical vaweguide 1000 μm. The monochromator is equipped with 3 gratings: 600, 1200 and 2400, which enable to regulate of wavelengths within: 300–800, 350–1100 and 190–700 nm, respectively. The grating blazes at 500 nm was used for our applications. The light from the output of the optical fibre passes through the quartz window in the lid of calorimetry container and is absorbed by the Pt-black. The experiments have been performed under isothermal conditions. The

temperature has been slightly higher (ca. 2–3 K above room temperature) than the room temperature. The stationary state of the calorimetry has been achieved after approximately twenty seconds of light irradiation. The experiments involved both types of lights, white and monochromatic light.

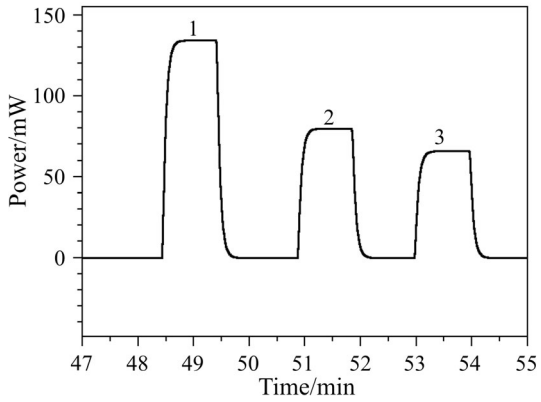

Fig. 3 Calorimeter response to irradiation of white light for three different diffraction gratings. 1 – diffraction grating 2400 g mm^{-1}, power 135 mW;
2 – diffraction grating 1200 g mm^{-1}, power 80 mW;
3 – diffraction grating 600 g mm^{-1}, power 66 mW

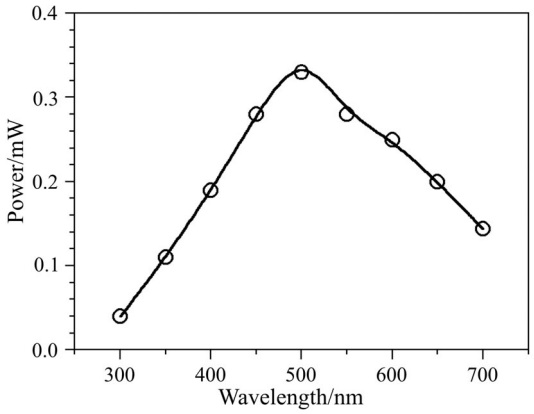

Fig. 4 Radiation power *vs*. wavelength for 2400 diffraction grating

Results and discussion

Figure 3 illustrates the determined values of the radiation power of white light in the case of three different diffraction gratings 2400, 1200 and 600. No drift of the 'base line' is observed. The steady-state was achieved in ca. 24±4 s. Determined light power values are 135, 80 and 66 mW, respectively. The dependencies of the light power on a

wavelength are shown in Figs 4–6 for the studied diffraction gratings 2400, 1200 and 600, respectively. Spectral radiance distribution of xenon source and application of blazed grating affect the dependencies radiation power on wavelength. It is well-known that blazed diffraction grating showed a high efficiency about blaze wavelength. Smooth curves with a well-developed maximum are observed for the diffraction gratings in Figs 4 and 6. On the other hand, the power characteristics of the diffraction grating 1200, presented in Fig. 5 is more complicated. In this figure, the results provided courteously by Jobin Yvon/Spex Instruments S.A. Inc., are illustrated by the line 2. As can be seen, both lines 1 and 2 show similar shapes. The difference in absolute values of light power results from different optical systems in experiments (different optical fibres, different optical path, etc.).

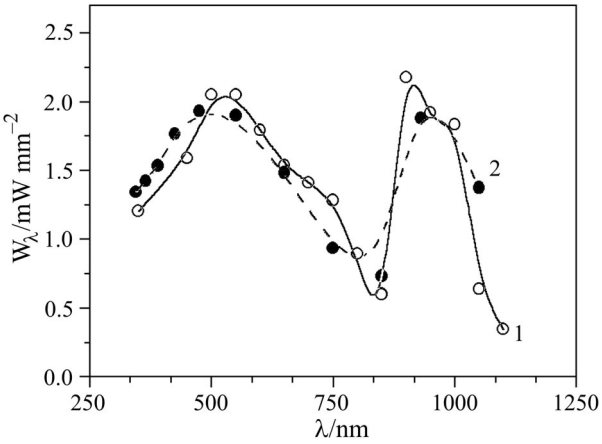

Fig. 5 Radiation power *vs.* wavelength for 1200 diffraction grating, 1 – this work, 2 – results provided by Jobin Yvon/Spex Instruments S.A. Inc

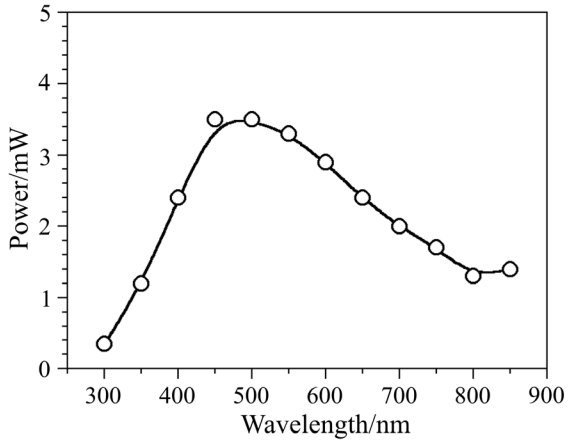

Fig. 6 Radiation power *vs*. wavelength for 600 diffraction grating

Conclusions

The incident radiation power on electrode surface of the commercial solar-simulated light source was determined by means of DSC. The described procedure, belonging to direct methods, gives opportunity to determine reliable calibration curves for radiation power *vs*. wavelength. Since the measuring signal is proportional to the amount of absorbed energy, the sensitivity remains independent of the wavelength. Application of the DSC equipment guarantees good accuracy of the measured property. This method allows to study processes of solar energy conversion and determines the efficiency coefficients of photoelectrochemical cells. The results of power application of the differential scanning calorimetry guarantees very high sensitivity of the measuring property, independent of the wavelength. The limitation for the practical use of this method is difficulty with achieving of the different configuration of commercial DSC equipment.

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This work is supported by the Polish State Committee for Scientific Research (KBN) under grant 4 T08A 025 24.

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