Using Thermopile as Densitometer for Measurement Optical Density for X-Ray Radiation Film Which Used in Dental Medicine

Qusay Kh Omer Al–Dulamey
BSc, MSc (Assis Lect)

Department of Physics
College of Science, University of Mosul

ABSTRACT

Aims: To encountered in using thermopile device (thermocouple) as densitometer for measuring optical density for X–radiation film which is used in dental medicine. **Materials and methods:** Americium–241(Am–241) 59.5keV was used to expose a number of dental X–ray films for different times to end with a variety of optical densities on them. **Results:** A comparison of the optical density readings between the densitometer and thermopile was made. **Conclusions:** The thermopile was capable to measure the optical density of any transparent polymer material while the densitometer can measure the optical density of the X–ray film only.
Key Words: Radiology, Densitometer, Dental X–ray film, Thermopile, Optical density.

INTRODUCTION

Thermopile detectors have some desirable characteristics that make them better suited for certain applications than are uncooled bolometers and pyroelectric / ferroelectric detectors[1]. Other properties of thermopiles may be found by Foote in 1979[1]. The Jet Propulsion Laboratory (JPL) thermopile linear arrays have been described in detail previously[2].

The thermopile is a series combination of thermocouples. One set of the thermocouple junctions is heat sunk to the detector case which is maintained at the ambient temperature. The other set of junctions is attached to a membrane that is thermally isolated from the ambient. The incident radiation is absorbed by the membrane, and the temperature of the membrane with the set of junctions attached to it changes in correspondence.

The energy is absorbed at the surface and must have time to spread through the material, be conducted to the ambient and allow the detector to come to a state of quasi–equilibrium. The speed of response or time constant can be controlled to some degree by design. The thermopile, of course, generates its maximum response or signal at DC. As the incident radiation is modulated, the response of most thermopiles starts to fall off significantly around 5 Hz and to unusable levels by 10 Hz. Thermopiles designed specifically for high speed operation can be used at somewhat higher frequencies or modulation rates.

Wireless integrated network sensors (WINS). This detector system includes a high sensitivity thin–film radiation thermopile and a micro power analog to digital converter (ADC) optimized for this unique system. The thermopile has an excellent responsively of 100 V/W and a normalized detectivity of 1.1 x 109 cm*Hz$^{1/2}$/W in vacuum. The ADC includes a chopper for low noise measurement of the low frequency infrared sensor output. The ADC provides greater than 9–bit resolution and DC stability at a micro power level of 30W)[3].

On each membrane are a number of Bi–Te and Bi–Sb–Te thermocouples running along narrow legs between the substrate and membrane. The detectors are closely spaced, with slits through the membrane separating the detectors from each other and defining the detector legs. Typical detectors have D values in the

range 1–2 x 109 cm* $Hz^{1/2}$/W and response times less than 100 ms. Thermopile detector arrays are currently being fabricated at JPL for the Mars Climate Sounder (MCS) instrument. MCS is a limb–sounding radiometer to fly on the Mars Reconnaissance Orbiter (MRO) mission, scheduled to launch in 2005. MCS will measure temperature, pressure, water vapor, and the combination of dust and condensates as a function of altitude in Mars' atmosphere in addition to polar radiative balance. Nine 21–element linear arrays of thermopile detectors, distributed between two focal planes in twin telescopes, sit behind spectral band pass filters spanning the wavelength range 0.3–45 microns[4].

The detection of X–rays is based on various methods. The most commonly known method are a photographic plate, X–ray film in a cassette, and rare earth screens. The X–rays photographic plate or film is used in hospitals to produce images of the internal organs and bones of a patient. Since photographic plates are not generally sensitive to X–rays, phosphorescent screens are usually placed in contact with the emulsion of the plate or film. The X–rays strike the phosphor screen, which emits visible light, which exposes the film. The emulsion still needs to be heavily doped with silver compounds and can be coated on both sides of the film or plate. After processing the X–ray film chemically, some times the specialist is interested in knowing the degree of blackness on different parts on the X–ray film. For this purpose, densitometer device is usually used. In this paper, an attempt to used a thermopile instead of a densitometer is tried. Then the readings of thermopile are compared with those of the densitometer.

MATERIALS AND METHODS

Description of Thermopile: Dexter Research Center was a leader in the manufacture of stable, high quality, high output radiation sensing thermopile detectors with a linear dynamic range from the UV to long wave IR. Thermopile detectors are passive radiation sensing voltage generating devices, that require no bias or cooling and do not emit any radiation. The detector's spectral absorption, that used in this study was flat from the ultraviolet to the far infrared. Spectral sensitivity was defined by the selection of optical band–pass filters. Thermopile output was generally in the micro–Volt to milli–Volt range depending on target size, temperature and radiance.

Thermopile detectors could be thought of as a series array of miniature thermocouple junctions connected in series as differential pairs. These differential pairs make up the cold junctions and the hot junctions, Figure (1). In fact, the hot and cold junctions are connected by alternating n–type and p–type materials, called "Arms" creating a See–beck effect between the junctions. A voltage which produced, proportional to the temperature gradient between the hot and cold junctions. For Thin Film based thermopiles, the arm materials are antimony Sb and bismuth Bi. For Silicon thermopiles, the arm materials could be alternating n–type and p–type Poly–Silicon or n–type with gold Au or aluminum Al.
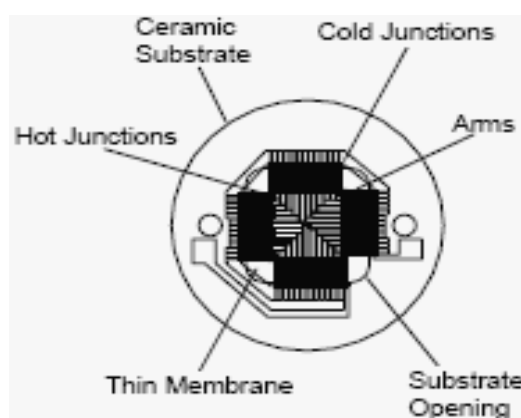

Figure (1): Key features of the Model 2M Thin Film thermopile detector[5].

The cold junctions were typically thermally connected to the detector package and are located around the perimeter of the substrate opening. The hot junctions were located in the center of the detector pattern and were coated with an energy absorber. The hot junctions defined the active area of the detector and were suspended on a thin membrane, thermally isolated them from the rest of the package [5].

Kodak Dental double emulsion X–ray film (3.1 cm x 4.1 cm) were used .These films were characterized by their high sensitivity and classified as E – class speed.

Seven films are used and irradiated by Am–241 source with activity 50 x10–6 Ci and energy 59.5 keV for exposure 24–100 hr, as shown Table (1). For the purpose of comparison, two sets of these films were used; the first set are processed manually, and the second set are processed automatically.

Table (1): Comparison between the densitometer and thermopile readings at 6 cm

Film Number	Exposure time(h)	Optical density= O.D.		Diff % between Densitometer and Thermopile reading
		Densitometer reading	Thermopile reading	
1	24	0.96±1.45	0.91±1.53	5.2
2	40	1.37±1.02	1.29±1.08	5.83
3	50	1.72±0.81	1.61±0.87	6.39
4	70	2.07±0.67	1.93±0.72	6.76
5	80	2.38±0.58	2.21±0.63	7.14
6	90	2.50±0.56	2.32±0.60	7.20
7	100	2.77±0.80	2.57±0.54	7.22

The experimental set up for measuring the optical density on the X–ray film that shown in Figure (2). It consisted of 275 W infrared, visible and UV–A emitter reflector lamp. The thermopile detector was situated at 0.4 cm from the lamp and connected to current meter whose scale was ranging from 0–500 mA .
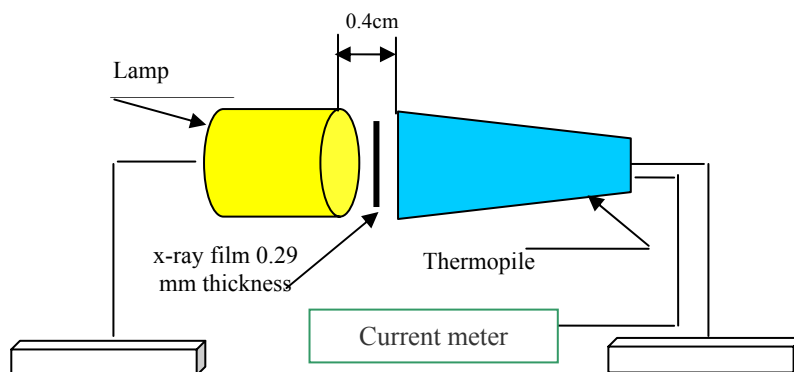

Figure (2): Experimental set–up.

Description of Densitometer: The densitometer was a device normally used to measure the optical density from spot to spot on the processed X–ray film, or from film to another. The densitometer used was of the type DT 1105[6] and consist of two units; the base unit type 305, and the optical unit type 205, Figure (3). The intensity of light passed through the X–ray film was measured by photodiode whose function is transforming the light incident on it into electrical pulses to be amplified by the amplifier which was connected to Digital Panel Meter (D.P.M.). The later

transformed the pulses into numbers proportional to the optical density of that particular spot on the X–ray film.

To calculate the optical density for X–ray film , the following relation is used

$$O.D. = Log \ \frac{I_o}{I_t} \quad \dots (1) \ ^{(6)}$$

Where : I_o , represents the intensity of the incident visible light of exposure film.

While I_t , represents the current intensity in the mA of the light passed through of exposure. D: represents the optical density on that small area which was a measure of the degree of blackness of that area . The error in measurement of any optical density by densitometer or thermopile equal to ± 0.01 experimentally.

Figure (3): The densitometer device.

RESULTS

An X–ray film of the type measured above is was processed chemically without exposure it to irradiation, and then its optical density; O.D. was read by the densitometer and found to be 0.13 which represents the background optical density reading of the X–ray film .

In comparison, the same film gave 303 mA thermopile reading when it was located between the lamp and the thermopile, Figure (2), while the reading of the thermopile was 400 mA without the film. Putting these figures in equation (1) gave O.D=0.12 for the background optical density which was so closed to the densitometer reading .

In this paper Am–241 radioactive source emitting gamma ray whose energy 59.5 keV was used to irradiate (7) X–ray films fixed at about 6 cm from the source and received radiation as illustrated in Table (1) and also emitting alpha particle whose energy 5.485 MeV.

CALCULATIONS

The error in the optical density reading the back radiation film and according to the (Squires Properties)[12] which contained diagram for the relationships between errors. The error in measurements of any optical density by Densitometer equal ± 0.01, so the error in the final optical density becomes as follow:

$$(\Delta Df) \ 2 = (\Delta D1)2 + (\Delta D2) \ 2 \quad \dots \quad (2)$$

Where ΔDf, final optical density error to a certain film.

ΔD1, error in the optical density for the same film.

ΔD2, error in the optical density for the back radiation film.

And by substituting instead of ΔD1 and ΔD2 by the value ±0.01 in the equation (2) results:

(ΔDf) 2 = (0.01)2+ (0.01)2

ΔDf = ± 0.014

Where as (± 0.014) represents the error in final optical density, and then we will calculate the relative error in the optical

density (O.D.) according to the following relationship:

$$\Delta O.Df/O.D. \times 100\% \quad \dots \quad (3)$$

For example the optical density relative error (0.26) as in Table (1), could be calculated according to equation (3) as follow:

$$\pm 0.014 /0.96 \times 100 \% =\pm 1.45 \%$$

In order to compute alpha range in air, by using following equation :

$$R(cm) = 1.24T(MeV) - 2.62 \dots\dots\dots\dots(4) \text{ }(7)$$

Where, R: range of alpha particle in air, T represent kinetic energy of alpha.

Put alpha energy instead of T in equation (4) and obtained 4.1 cm which represented alpha range and less than (6 cm).

DISCUSSION

Am–241 radioactive source was used because the energy it emits was close to the energies currently used in dental radiography. X–ray tubes in dental radiography is working normally in the range (50–70) kVp [8]. The function of thermopile is similar to that of the densitometer regarded optical density measurement. Table (1) showed that the maximum difference between the densitometer and thermopile reading was 7.2%. The selection of (6 cm) distance between the source and the film was because for distances less than (6 cm), alpha particles will contribute to the film refer to equation (4), thus the alpha range equal 4.1 cm; and obviously the exposure time is long for distances over (6 cm). Further to that, the aim was to have all the exposures on the "region of correct exposure" of the characteristic curve of (E–class speed) film, but the alpha effect appeared at the distance 3cm between the radioactive source and dental X–ray film where, the optical density of film equal O.D.=2.45 by densitometer and with thermopile O.D.=1.83.

The thermopile reading was more stable than the densitometer reading. This is because of the large quantity of heat developed on the densitometer as compared to the thermopile.

In this study the manual chemical processing were used for all films, while another previous papers they used two method of chemical processing. The results of automatic chemical processing for previous papers more sensitive comparison with our results, because the error ratio with automatic chemical processing less than manual chemical processing., therefore the types of methods for chemical processing are effect on the results, especially comparison with (5) and (10) as shown in Table (2).

Table (2): Comparison between present work with previous search

Exposure Time/h at 3 cm	Researcher	Optical density measurement	Chemical processing	Radioactive source	Detector	Optical density
40	(Mahok &Al–Dulamer,2006) [9]	densitometer	Manual	Am–241	Dental–ray film	1.29±1.08
40	(Al_Badrani & Al–Dulamer, 2008) [10]	densitometer	Automatic	Am–241	Radiographic film	1.2± 16
40	(DRC,2006)	IR thermopile	Automatic	X–ray tube	Dental–ray film	1.28± 1.09
40	(Kodak,2002)	densitometer	Manual	X–ray tube	Dental–ray film	1.4 ±1.0
40	(Present work,2008)	thermopile	Manual	Am–241	Dental–ray film	1.38± 1.01
		densitometer	Manual	Am–241	Dental–ray film	1.85±0.75

Finally, another measurement achieved at 3 cm between thermopile and densitometer with radioactive source which covered by thin paper. From Table (2) the optical density measurement for present work nearly from previous search at same

exposure time especially with Dexter Research Center(DRC),2006 and Kodak, 2002 because the error ratio obtained very small and less different percentage 6.3 % comparison with Dexter Research Center.

CONCLUSIONS

The thermopile is available and cheap as compared to the densitometer. Finally, the thermopile is capable to measure the optical density of any transparent polymer material while the densitometer can measure the optical density of the X–ray film only.

REFERENCES

1. Foote MC, Kenyon M, Krueger TR, Chacon R, Jones EW, Dickie MR, Schofield, Cleese DJ. Jet Propulsion Labora*tory, California Institute of Technology, Jet propulsion laboratory, California Institute of Technology.* 1979; 1.
2. Chang DT, Gladney CA, William JK. Micro power High–Detectivity Infrared Sensor System. *Electrical Engineering Department, University of California, Los Angeles Los Angeles.* 1995; 2.
3. Catalog A2TPMI Datasheet / Thermopile with integrated signal processing circuit. *PerkinElmer Optoelectronics GmbH.* 2003; Pp: 9–11.
4. Infrared and Electro–optic Technology. *Physics of Electro–Optic Detectors, Everett Companies LLC, Phoenix, Arizona, USA.* 1999; 7.
5. Dexter Research Center (DRC). Introduction to Thermopile Detectors, *www. DexterResearch.com.* 2006; 1–2.
6. Fugate ME, Professor RT. Radiographic Technique II, Course Packet, Radiography Program, *Santa Fe Community College, Gainesville.* 2005; 649.
7. Al–ahmmead, KhA. Introduction in Health Physics, Education College, University of Mosul, 1993; 41–44.
8. Kodak Dental Film–Data sheet, Germany. 2002; P: 1.
9. Mahrok MF, Al–Dulamey QKH. X–ray Hazard from Colour Television Sets and Video Display Terminals. *Rafidain Journal of Science.* 17 (2) physics Issue, 2006; 1–5.
10. Al–Badrani, Mohsen WI and Al–Dulamey Q KH. The effect of fluorescent intensifying screen CaWO4 on radiation dose received during X–radiography. *Education & Science Journal,* 2008; 2.