PHOTOTHERMAL AFFECTS OUR LIVE

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ABSTRACT

The photothermal effect of solid was first discovered by Alexander Graham Bell in 1880 while its application on determining the type of gaseous was recognized in 1903. However the application on solid only began in 1973 after Parker discovered it accidently during the characterizing of gas with photoacoustic cell. Following this, the research activities on solid have exploded by its flexibility in photothermal detections and can be applied in various applications. Here the review on photothermal research activities on sample characterizing in UPM and others are presented. Also included are the future direction and challenges in photothermal research.

INTRODUCTION

The photothermal (PT) effect of solid was first discovered by Alexander Graham Bell in 1880 during his experimentation with long-distance sound transmission. Through his invention, called "photophone", he transmitted vocal signals by reflecting sun light from a vibrating reflector or mirror to a solar cell receiver, selenium (Bell, 1880). As a result of this observation, he noticed that sound waves were generated directly from a solid sample when exposed to sunlight beam that was rapidly interrupted or modulated with a rotating slotted disc (Bell, 1881), see Figure 1. Here he heard sound with a *stethoscope* contacting the sample. He observed that the resulting acoustic signal was dependent on the kind of the material and reasoned that the effect was caused by the absorbed light energy, which subsequently heated the sample.

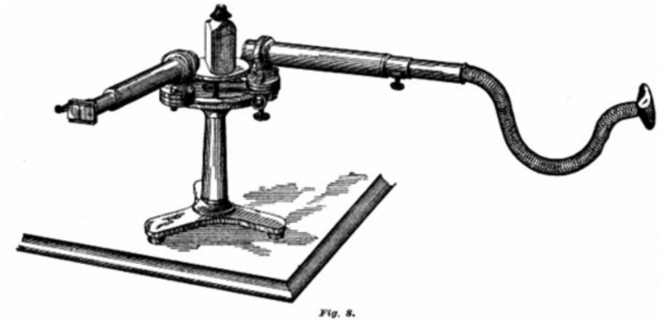


Figure 1 Bell's instrument for observing the photothermal effect. (http://fys.kuleuven.be/atf/Research_themes/rt_photoacoustic/rt_photo_pha)

Nowadays, this effect can be explained as an excitation upon receiving an electromagnetic radiation (light) energy and de-excitation of electron between energy levels in atom. In the de-excitation the electron can go either through non-radiative or radiative transition. The non-radiative route transition can produce vibration or heat in the solid surface atoms; i.e. as happened on black motorcycle seat as it turns hot when it is exposed under the sun.

The utilization of PT effect on gas had started since 1903, where most of type of gasses can be detected by using the microphone as a detector and therefore known as photoacoustic (PA) technique as microphone is used for detection. Here they utilized the sensitivity of certain gas with certain light wavelength. However its application to solid had not really begun until 1973 when Parker (1973) discovered that in the PA measurement of gas, even for gas of non infra-red absorbing the sound was produced. He concluded that it came from the PT effect of solid PA cell glass window. Later researchers discovered that other than microphone detector, a series of PT detectors can be employed such as piezoelectric detector, pyroelectric PVDF film detector, and various means to detect changes of material refractive index caused by PT effect.

After this discovery, the PT study on solid was suddenly exploding because apart of being detected by various means, it can be applied to many fields of study such as nondestructive evaluation, thermal study, chemical reaction, spectroscopy for analytical chemistry and semiconductor materials, thermophysical properties and characterization of materials, optical material, thin films and devices, nonlinear phenomena, instrumentations, biological and medical, and agricultural and environmental applications. Following the discovery also, there was a bi-yearly conference set-up to report its progress and was named as "The International Conference on Photoacoustic and Photothermal Phenomena", and photoacoustic journals to report many research activities related to this effect.

WHAT IS THERMAL WAVE?

How one can hear the sound with hearing aid when a chopped or modulated light illuminate the solid? The answer is as follows; (i) the PT effect produces the conversion of the absorbed modulated light into heat energy, (ii) then the temporal changes of the temperatures at the point where radiation is absorbed, i.e. rising as radiation is absorbed and falling when radiation stops and the system cools, (iii) expansion and contraction in air that in contact to solid occurs following these temperature changes, which are "transferred" to pressure changes. The pressure variations, which occur in the particular wavelength where light is absorbed, propagate within the sample body and can be sensed by a hearing sensor attached to it. While in the solid at the same time the heat diffusion occurs and varies because of light modulation. Both air pressure and heat diffusion variations are like wave and therefore it is termed as thermal wave. The thermal wave can be detected by PT detector or microphone. In the transient regime, a short duration light pulse (in particular laser or flash light) is illuminated onto a particular liquid or solid surface and the radiated infra-red is detected by PT detector such as pyroelectric films, infra-red detector such as cooled HgCdTe.

Mathematically the thermal wave can be expressed as Eq. (1).

$$Y(x,t) = Ae^{-\mu x}\cos(\omega t - \mu x) \qquad (1)$$

Here μ is the thermal diffusion length (cm), ω is the frequency (rad s^{-1}), t and x are time and distance respectively. For an opaque sample, the thermal diffusion length or the depth of the heating section can be altered by changing the chopper frequency; i.e. the faster the chopper the shorter the heating section is. For transparent or semi-transparent sample, the light can penetrate the sample (solid or liquid) to a certain length depending on its transparency and during penetration the light is also producing thermal wave.

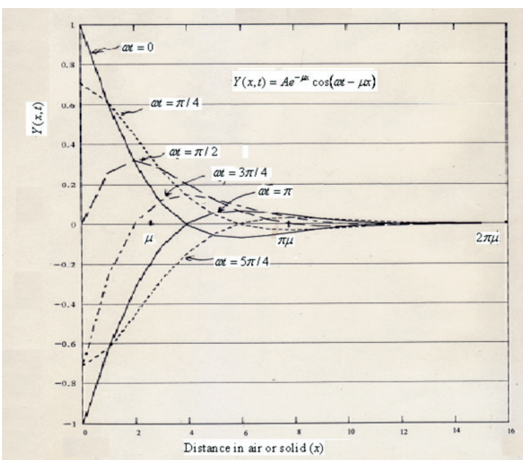


Figure 2 The profile of thermal wave as time progresses (or as phase ωt changes)

The profile of thermal wave can be presented as in Figure 2. Here it can seen that by continuosly changing the time which changes the phase ωt of cosine term, its profile moves to the right but with extremely reduced amplitude.

For a layered sample subjected to a modulated light, the signal produced by a detector normally obtained by solving heat diffusion equation of each layer of the sample plus the continuity equation at every interface of layers (Delenclos et al, 2001). The other method is by using thermal wave interferometry (see Figure 3) similar like treating a light beam when it crossing many semitransparent layers of material (Bennett and Patty, 1982; Minamide et al, 1988; Azmi et al, 2006). The later approach is much easier because it does not need to solve difficult heat transfer equations of many layers in order to reach the final expression for the average PE signal voltage.

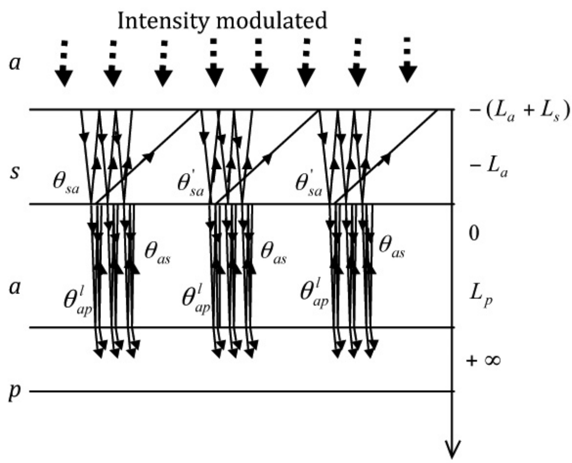
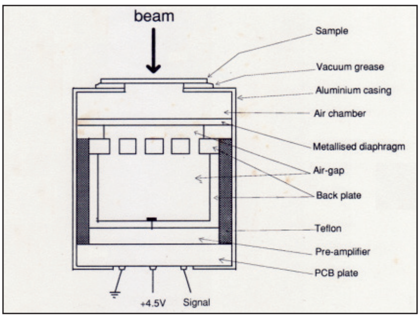


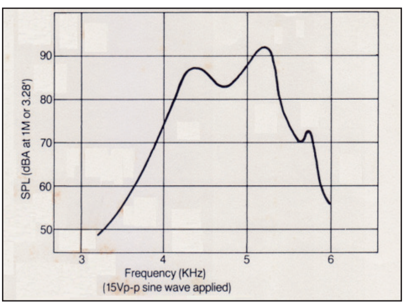
Figure 3 One-dimensional configuration of photopyroelectric cell with the route of thermal wave showed; s is sample, a is air, p is PVDF film, b is backing. (Azmi et al, 2006)

Detection Methods

For the PA detection, as mentioned earlier on, it can be measured with a microphone attached to a PA cell that contains gas, liquid or solid sample. The microphone can be from a very highly sensitive and expensive to a reasonably sensitive and low cost microphone. The later can be a small electret microphone as can be seen in Figure 4(a) and its response is from a few Hz up to 6.5 kHz, Figure 4(b). The example of simple "closed cell" and "small volume" PA cell for detection can be seen in Figure 5. The electret microphone also can be used directly for detection where the sample is located on top of it, and in this situation it is termed as an "open cell" detection, Figure 4(a).



(a)



(b)

Figure 4 Electret microphone (a) and its typical response (b)

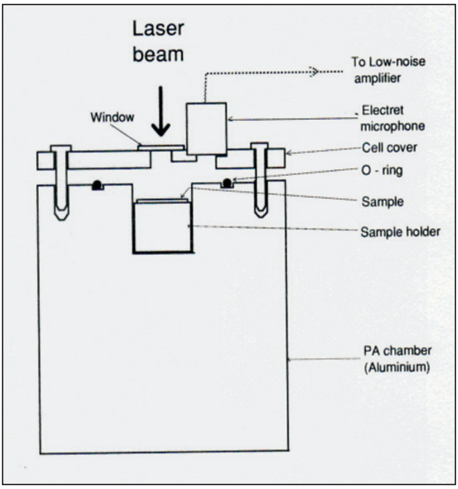


Figure 5 The small volume PA cell

For PA spectrometer, the light source is varied with a monochromator before illuminating the sample of either gas, liquid and solid in the cell. If monochromatic beam is used then PA cell can be used to detect certain gas concentration in the chamber that resonance with the gas. For liquid and solid it used to detect trace element as well as to determine sample thermal diffusivity.

For other PT detectors; piezoelectric, polyvinelydine defluride (PVD) film, they can be arranged as in Figure 6 for thermal wave detection. Referring to the illuminating light direction, the sample; gas, liquid or solid, can be coupled to the front or the back of the detector. Therefore the detection holder or cell is termed as either “Front-” or “Back-” configuration systems.

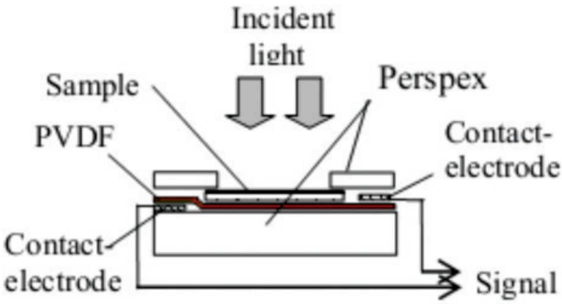
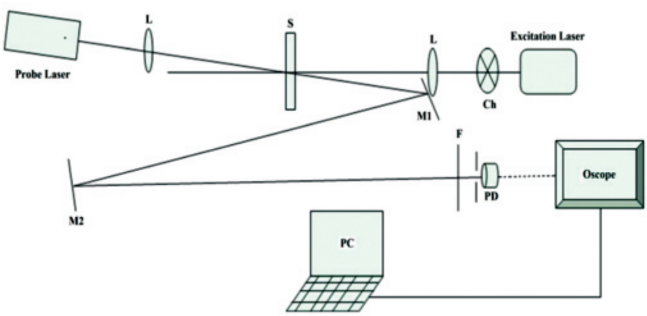


Figure 6 Schematic diagram of sample-PVDF holder

The PT also affects the refractive index of sample. To measure this change, the detection method utilizes the bending of probe or detection beam when passes through the vicinity of the area hit with the excitation beam. Among the method used with reference to this phenomenon are thermal lens, PT beam deflection, Z-scan, mirage set-up, etc (see Figures 8, 9, 10, 11.).



(a)

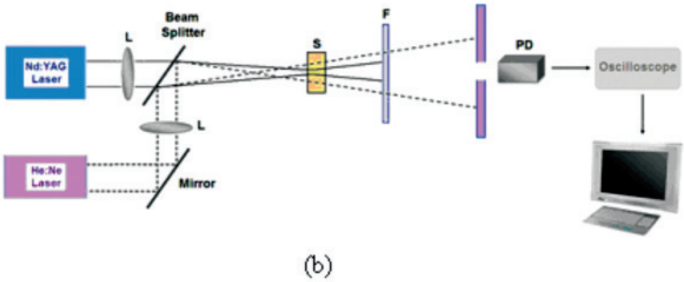


Figure 7 Schematic diagram of Thermal lens experimental set up using (a) CW excitation beam (Reza et al, 2011), (b) pulsed excitation beam. (L = lens, S = sample; F = filter; PD = photodiode detector) (Reza et al, 2012).

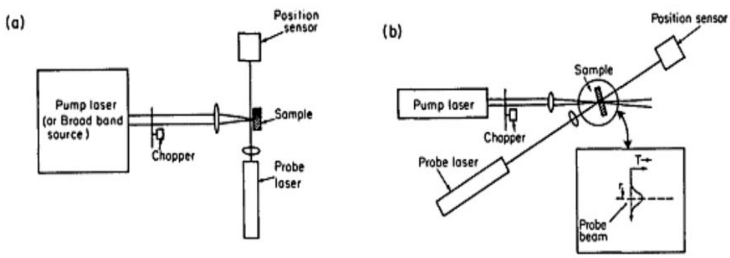


Figure 8 Photothermal Beam Deflection method (a) transverse, (b) collinear. (Jackson et al, 1980)

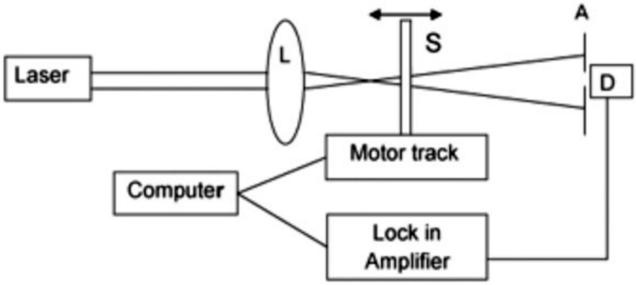


Figure 9 *Z*-scans setup. L = lens, S = sample, A = aperture, D = detector. (Shahriari et al, 2010)

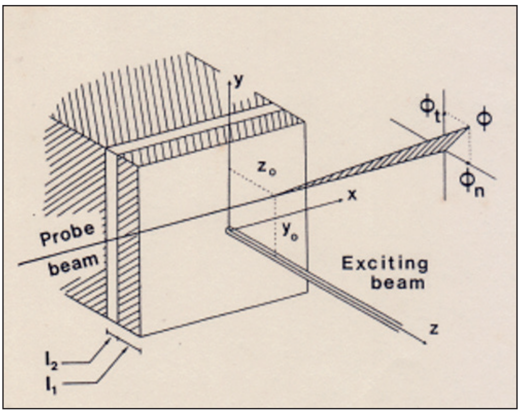


Figure 10 Geometry employed in mirage detection of semi-infinite slab. (Salazar et al., 1991)

On the second category, transient heat regime, the detection is via infra-red wave which is produced by the laser pulse or camera flash and the detectors are CdHgTe (Moksin et al, 1999), PVDF detectors (Moksin et al (2013).

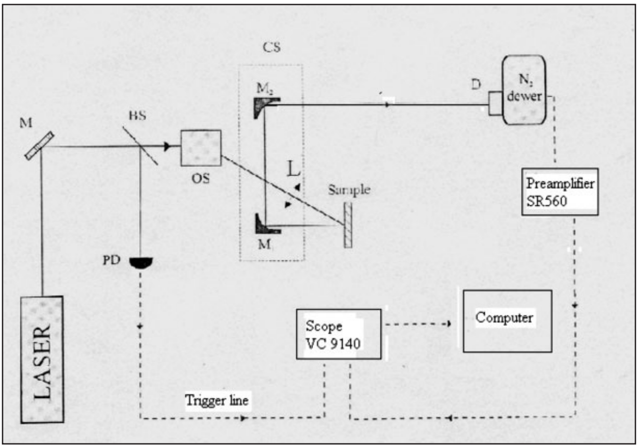


Figure 11 Schematic diagram of transient heat detection. D=CdHgTe detector, BS = beam splitter, OS = optical system, PD = photodetector, CS = signal collection system. (Moksin et al, 1999).

APPLICATIONS OF PHOTOTHERMAL EFFECT

Spectroscopy

In spectroscopy, normally a high power light source up to 1 kW is used. The light beam is passed through a monochromator then to sample, and the detection is via a sensitive microphone, or other PT detectors. The detector, as previously mentioned, can be in the Front- or Back-configurations.

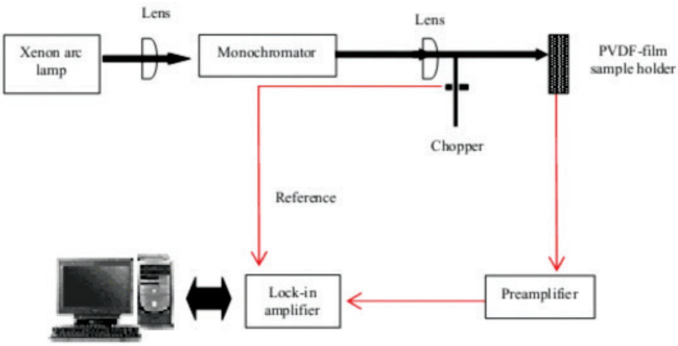
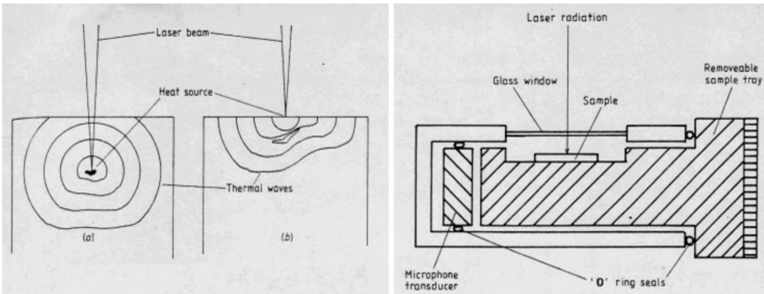


Figure 12 Schematic diagram of photopyroelectric spectrometer. (Azmi et al., 2004)

The advantage of the system over the conventional spectrometer is that it can be used for partially opaque solid sample. Here carbon spectrum from the source is used as a reference spectrum and therefore needs to be divided with sample spectrum to obtain the true spectrum. In UPM we have developed this photopyroelectric spectrometer by using a high power 1 kW Xenon arc source, using both motor control and automated monochromators, and interchangeable photopyroelectric cell detector, see Figure 12. It can be used to investigate the photochemistry of leave (Liaw and Azmi, 2008), and doped polymer (Azmi et al, 2001; Azmi et al, 2002(a)). Here it can be seen that for normal green leave the spectrum is highly absorbed from UV to nearly green region. Trace element such as tellurium in liquid can be detected as low as 3 ppm in liquid can be detected in PA spectroscopy (using microphone) (Nomura et al, 1982). Through a certain manipulation of the semiconductor spectrum it can be used to determine optical band gap of semiconductor due to dopping in ZnO based varistor ceramic (Azmi et al, 2002(b); Azmi et al, 2004; Azmi et 2005(a); Azmi et al, 2005(b); Azmi et al, 2006(a); Azmi et al, 2006(a); Zahid et al, 2008(a); Zahid et al, 2008(b); Zakaria et al, 2008; Zahid et al, 2009; Zahid et al, 2011(a); Zahid et al, 2011(b)). Here the band-gap increases or decreases depending on the dopping involved in the ZnO ceramic. It also can be used to obtained the spectrum of laser active component such as neodymium oxide (Liaw 2007) and it is noticed that the based line of the spectrum decreases with the increase of light chopping frequency.

Nondestructive Evaluation

Imaging is one of the way to inspect the defect in solid sample and among the earliest attempt for imaging by using PA method done by Kirkbright et al (1984). Here a modulated laser was focused onto a sample placed in a PA cell by and the sample was raster scanned relative to the beam. The thermal wave is scattered when hitting a defect in transparent or opaque solid, see Figure 13(a) and the typical arrangement of sample in PA cell can be seen in Figure 13(b). The raster scanning is normally by moving the sample or the cell with respect to sample, and the typical image formed from an opaque sample with circular subsurface damage can be seen in Figure 14. Other method is by raster scanned the beam with respect to sample by a combination of two controlled moving mirrors for x and y direction (Wang et al, 1990).



(a) (b)

Figure 13 (a) The generation of imaging information by the interaction of thermal waves with physical structures for transparent and opaque samples, (b) Schematic diagram of a photoacoustic gas cell. (Kirkbright et al, 1984)

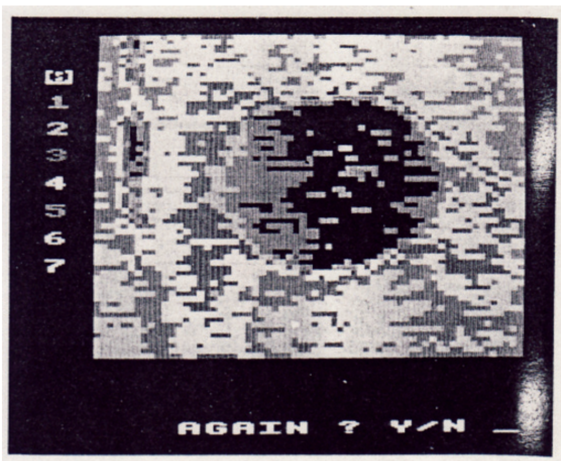


Figure 14 Phase image of a subsurface defect in an opaque sample with modulation frequency 100 Hz. (Kirkbright et al, 1984)

Among the interested sample is a gold coated polymer film subjected to atomic oxygen (ATOX) in laboratory (Azmi et al, 1994). Here, it is placed onto a piezoelectric (PZT) detector in the scanning system, see Figure 15. To create an "undercut" damage, before exposed to ATOX the gold coating was deliberately scratched to allow ATOX to attack the polymer (Williams et al, 1993), see Figure 16. The possible undercut mechanism on polymer (alkanes and alkenes) by ATOX can be through abstraction, replacement, and insertion followed by recombination and fragmentation to become volatile materials (Banks and Rutledge, 1988; Azmi Zakaria, 2001). In the image, it displays the undercut defect underneath the metal coating that cannot be seen optically as shown in Figure 17 (William et al, 1993. The scanning by incorporating the electret microphone (Figure 4(a)) instead of piezoelectric also can be done in the system (Azmi et al, 1995; Azmi et al, 1997).

The light beam can be replaced by an electron beam. The easiest way to conduct this is by using a scanning electron microscope but by modulating the electron beam and fitting a PT detector underneath the scanned sample. Also, the scanning depth in the sample can vary by changing the modulation frequency and this means that the researcher can see the sample images at various depths (Salazar et al, 1991). By having both PT and electron beam detectors, researchers can study the surface SEM image as well as the sub-surface PT image.

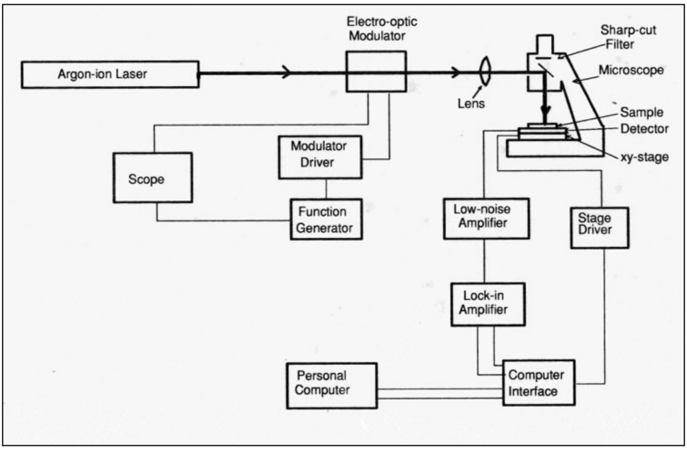


Figure 15 Scanning photothermal microscopy system

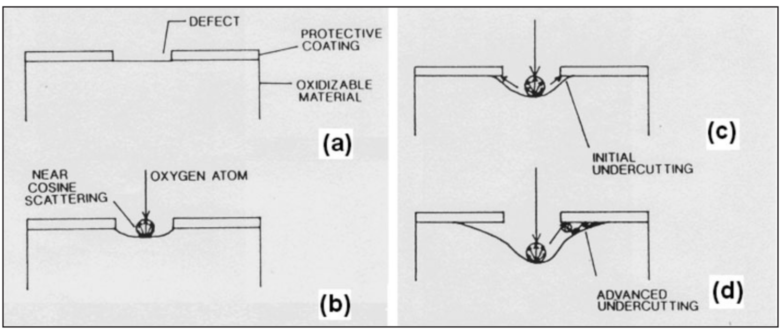
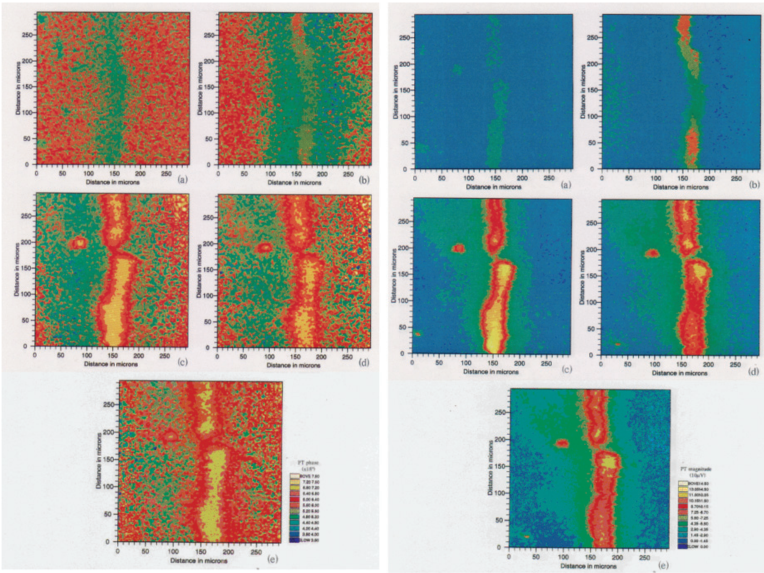


Figure 16 A possible scenario for undercutting of a defect coating in an ATOX environment. (Banks and Rutledge, 1988)



(A) PZT phase images of a deliberately scratched gold-coated Kapton sample scanned at 2 kHz: (a) unexposed, (b) exposed to a fluence of 24.6x10^{20} atom/cm^2. The phase images of the last exposure sample exposed to a fluence of 28.3x10^{20} atom/cm^2 and scanned at different light chopping frequencies (c) 2.0 kHz, (d) 1.3 kHz, (e) 0.9 kHz.

(B) PZT magnitude images of a deliberately scratched gold-coated Kapton sample scanned at 2 kHz: (a) unexposed, (b) exposed to a fluence of 24.6x10^{20} atom/cm^2. The magnitude images of the last exposure sample exposed to a fluence of 28.3x10^{20} atom/cm^2 and scanned at different light chopping frequencies (c) 2.0 kHz, (d) 1.3 kHz, (e) 0.9 kHz.

Figure 17 PZT phase and magnitude image (Williams et al, 1993)

The other way of imaging for non-destructive evaluation is by using a camera (InSb detector) that is sensitive to infra-red radiation. The light source can be expanded laser or a high power light source. For a typical sample black coloring material of low conductivity, e.g. bakelite, with back drilled hole defect. After flashing with radiation the image taken by camera and by using a frame grabber software the image can be seen Figure 18 (Almond et al, 1997).

With this technique one can inspect delamination on paint coating on metal painted surface.

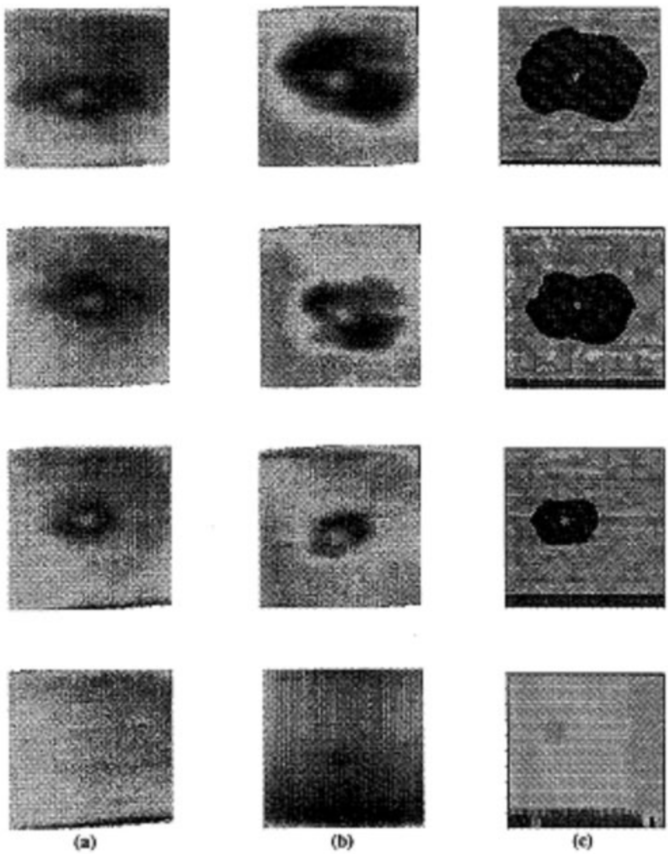


Figure 18 Transient thermograph images of 5J, 3J, 2J and 1J impact damage, [column (a)] from impact face, [column (b)] from back face compared with ultrasonic C-scan images [column (c)]. Image area is about 40×40 mm. (Almond et al, 1997).

Aircraft fuselages are assembled using a variety of different materials and fasteners such as aluminum and rivets, honeycomb structures, carbon-fiber-reinforced plastics, and other composite materials. Subject to constant temperature changes, pressurization and depressurization, vibration, and high wind loads, material fatigue occurs. This can cause deriveting, impact damages, cracking, and body delamination.

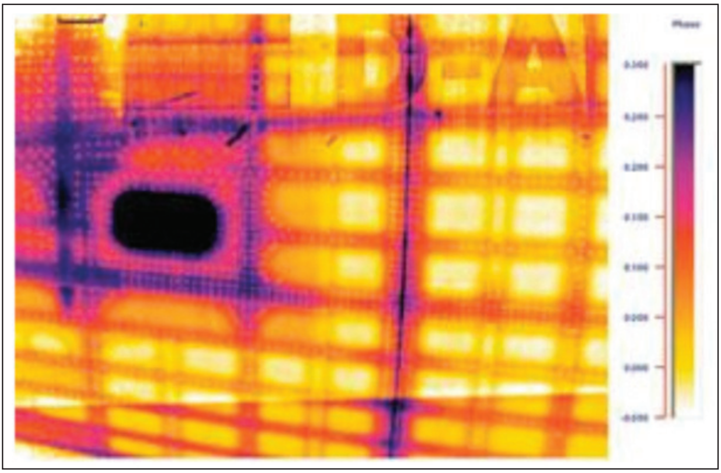


Figure 19 Fuselage inspection of a Boeing 737 using lock-in thermography shows the skin lap joints, stringers, doublers, and rivets. This image shows no defects. The frame station and the frame Tithe window appear in a darker color, an indication that they are made out of thicker material. (Vision Systems Design)

To check for these defects, the thermograph system that utilized PT effect is used to inspect several surface areas of the fuselages. This is by heating the exterior to about 40^{o}C using an array of high-power modulated halogen lights scan not to cause damage to the fuselage. The system measures and evaluates differences in the temporal behavior of the heat at the object surface, and defects appear. The typical image of fuselage inspection by thermograph can be seen in Figure 19. PT image can reveal the mark or stamping on metal surface even it has been removed. This is because the change in density due to stamping pressure still exists and thus can be detected in PT image. Scanning image can be taken at different depths by varying the thermal diffusion length or the modulation frequency to inspect faults solid, layers in layered material, and homogeneity in ceramic.

By illuminating a carbon black sample in a PA cell by a modulated laser beam laser power can be measured. A good linearity between known laser power and PA signal can be seen in Figure 20. The percentage of deviation laser power measured is small (less than 5%) for power up to 10 watt if the beam modulated at high frequency (300 Hz) (Satheeshkumar and Vallabhan, 1985).

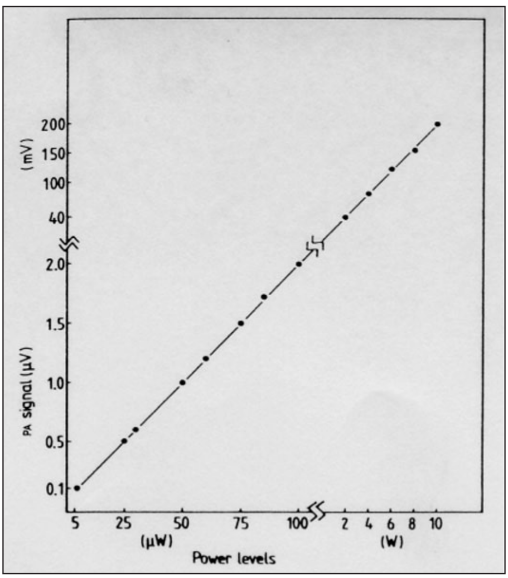


Figure 20 PA signal with power level.
(Satheeshkumar and Vallabhan, 1985)

Thermophysical properties and Characterization of Materials

Here thermal properties such as thermal diffusivity, thermal conductivity and thermal effusivity are measured. By laser flash method, i.e. transient method, the transient signal PT signal is analysed to obtain thermal diffusivity. By laser modulation method, i.e. the laser is chopped continuously by a rotating blade and is illuminating the sample. By plotting PT signal (amplitude or phase) versus frequency the thermal diffusivity can be determined. Materials normally used are conductors, insulators, ceramics, semiconductors, liquids and gaseous.

For solid, the thermal wave can be measured at various lateral distances on the sample between laser illuminated line and pyroelectric sensor position, see Figure 21. Here, the solid thermal diffusivity is obtained from the gradient of the plot of PT signal versus the lateral distance. The example metal samples that have been tried are aluminium, copper and spray paint with values 0.809, 1.128 and 1.547x10^{-3} cm^{2}s^{-1}, respectively.

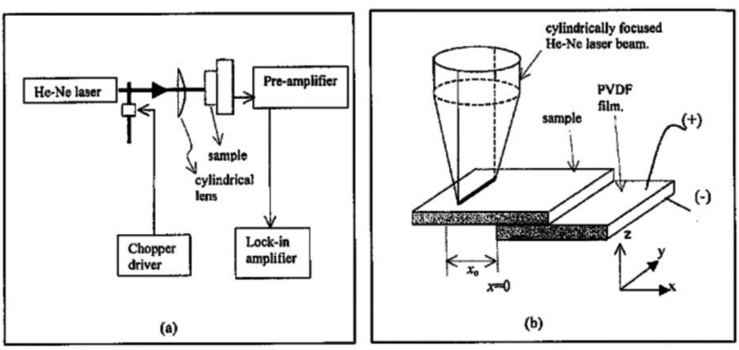


Figure 21 Experimental setup. (Azmi et al., 2002)

Normalisation of the PT signal in measuring thermal diffusivity eliminates the number of media parameters of pyroelectric cell that otherwise need to be known before one can determine the thermal diffusivity of sample. With the appropriate sample-pyroelectric detector dimension, the thermal diffusivity of any solid sample is readily being determined by this procedure and the apparatus for it can be seen in Figure 22. The method is tested for aluminum, copper, and nickel (Azmi et al, 2004).

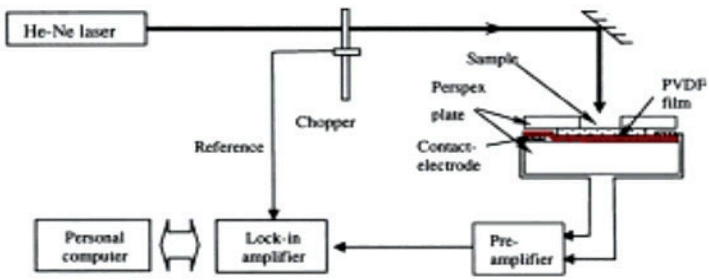
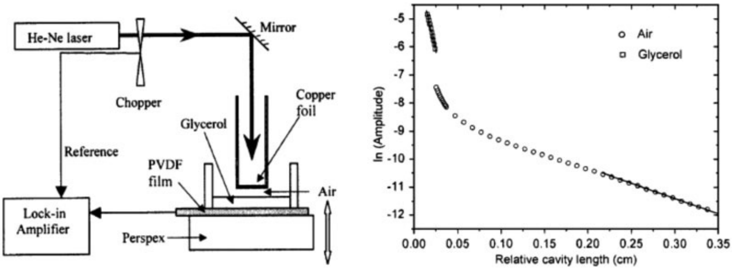


Figure 22 Schematic diagram of pyroelectric experimental setup. (Azmi et al, 2004)

The thermal-wave interferometry is a simple way of obtaining a model to evaluate thermal diffusivity of two media by using a thermal-wave resonator cavity (TWRC) technique, see Figure 23. This kind of thermometry for thermal wave was firstly employed by Bennett and Patty (1982) and in this technique the scanning is carried out by distance rather than by modulation frequency. In the scanning the copper foil that acts as thermal wave generator is moved towards the PVDF film detector. By using the model the thermal diffusivity of air and glycerol have been measured in single scanning and the values obtained close to the literature values (Azmi et al, 2006).



(a) (b)

Figure 23 (a) Schematic diagram of the experimental setup. (b) The amplitude of the pyroelectric signal on the cavity length for the two layer fluids: air and glycerol. The solid lines are the best-fit results of the experimental data. (Azmi et al., 2005)

In the normal PT technique, a precise control of thermal coupling fluid between the solid sample and the sensor is sometimes difficult, and yet an important factor in sample characterization. By using a non-contact pyroelectric configuration for solid thermal diffusivity measurement by considering the thermal wave interference was carried out, Figure 24. Here the thermal wave interferometry, Figure 3, to pyroelectric signal generation has been adopted in a thermally thick regime for a nondestructive testing. The normalization procedure has been used to eliminate a number of media parameters of pyroelectric cell that otherwise needed to be known before one can determine thermal diffusivity of the sample. The thermal diffusivities obtained for Al, Cu, and Ni samples (Azmi et al, 2006).

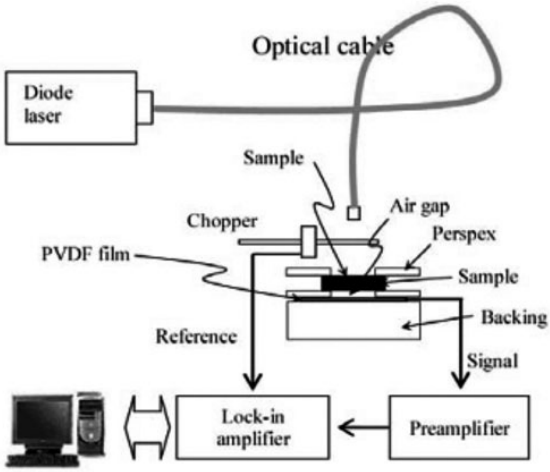


Figure 24 Measurement of thermal diffusivity using Non-Contact pyroelectric method. (Azmi et al, 2006)

From the previous idea, Figure 24, of using fiber optic, the TWRC technique then has been modified to replace the metal (copper) foil with metalized fiber optic tip to generate thermal wave. By this means the cumbersome in optical alignment in free space can be avoided. The system is termed as fiber optic-TWRC, or shortly as FO-TWRC, Figure 25. To obtain liquid thermal diffusivity the scanning, as in the conventional TWRC technique, was done by varying the distance or cavity length, i.e. by moving the fiber tip with respect to pyroelectric detector in liquid media (in a thermally thick regime). The thermal diffusivity value of water obtained by this technique agrees well with the values obtained by the conventional TWRC technique. This technique has a potential to be used in thermal diffusivity measurement of small liquid volume (Azmi et al., 2007) and its reliability for various liquids has been tested (Noroozi et al, 2010).

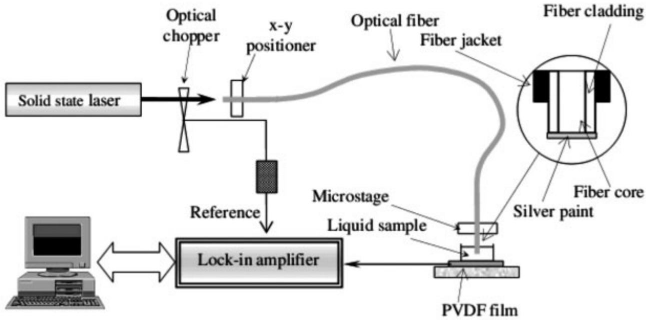
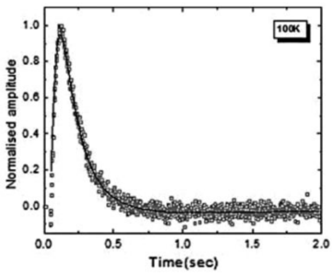
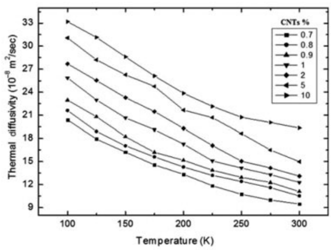


Figure 25 Schematic diagram of FO-TWRC technique. (Azmi et al., 2007)

On the example of transient technique, the thermal diffusivity can be obtained by a simple photoflash technique using a PVDF film detector. The sample is carbon nanotube (CNT) composites and the effect of low temperature on thermal diffusivity has been observed. The transient PT signal and thermal diffusivity values of sample at various temperatures can be seen Figure 26 (a) and (b), respectively. The results showed that thermal diffusivity of CNT-filled PVDF film composites is found to have consistently increased with increasing the CNT concentration or decreasing temperature. For the case of insulators with dominant thermal carrier is phonon, as expected.



(a)



(b)

Figure 26 (a) The transient signal by PVDF detector at the back of sample after photoflashing (b) The thermal diffusivity curves of sample at various temperature. (Moksin et al, 2013)

The pulsed laser thermal lens technique was used to study the thermal diffusivity of fluids containing copper nanoparticles prepared by γ-irradiation method. The samples were prepared for the different concentrations of Cu precursor at 20 KGy dose. A Q-switched Nd-YAG pulsed laser of wavelength 532 nm was used as an excitation source and He-Ne laser was used as a probe beam in the present thermal lens experiment. The typical thermal lens signal of sample of nanoparticles in glycerol can be seen in Figure 27. It was found that the thermal diffusivity of the solution depends on the density of Cu nanoparticles (Reza et al, 2012). Thermal diffusivity of fluid containing silver nanoparticles, that was prepared similarly, with CW diode laser (514 nm, 80 mW) excitation (Figure 7(a)) also was carried out (Reza et al, 2011).

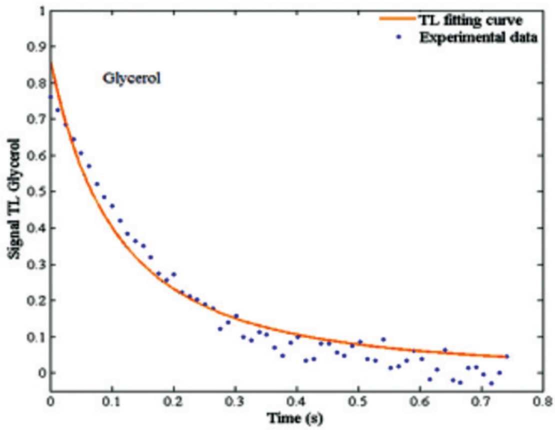


Figure 27 The thermal lens signal obtained by pulsed excitation. (Reza et al, 2012)

Application in Biology and Agriculture

The FTIR Infrared PA spectroscopy is used to determine the mid-infrared vibrational modes of biodiesel and vegetable oils to find the ability of separating glycerol from bio-diesel and to find the degradation effect after frying (Lima el al, 2008). The effect of radiance levels of sunlight in growth such as height, leaf area and number of leaves and photosynthetic activity of plant *Costa spicatus*. PA measurements are performed in order to evaluate comparatively the photosynthetic activity rate of plant submitted to different light intensities. The PA signal is related to the conversion of absorbed radiation into heat by using a white light light source (tungsten lamp, 250 W) modulated at 17 Hz. The measurements are performed *in vivo* using an open PA cell (Compos et al, 2008).

THE FUTURE CHALLENGE

The most important challenge ahead is on the Photoacoustic Tomography which is not yet fully developed for routine biomedicine application. The advantage of it is that it leaves no damage to the subject as no high energy em radiation is used and thus leaves no damage to the subject. In PA imaging, non-ionizing laser pulses are delivered into biological tissues. Some of the delivered energy will be absorbed and converted into heat, leading to transient thermoelastic expansion and thus ultrasonic emission in the order of MHz. An ultrasonic transducers then detect the generated ultrasonic waves. It is known that optical absorption is closely related with physiological properties, such as hemoglobin concentration and oxygen saturation (Grinvald, 1986). As a result, the magnitude of the ultrasonic emission or PA signal, which is proportional to the local energy deposition, reveals physiologically specific optical absorption contrast. 2D or 3D images of the targeted areas can then be formed (Xu and Wang, 2006). Figure 28 is a schematic illustration showing the basic principles of PA imaging. The optical absorption in biological tissues can be due to endogenous molecules such as hemoglobin or melanin, or exogenously delivered contrast agents. Since blood usually has orders of magnitude larger absorption than surrounding tissues, there is sufficient endogenous contrast for PA imaging to visualize blood vessels, Figure 29. Recent studies have shown that PA imaging can be applied *in vivo* for monitoring tumor related to blood vessel, mapping of blood oxygenation, imaging functional brain, and detection of skin melanoma etc. (Xu and Wang, 2006)

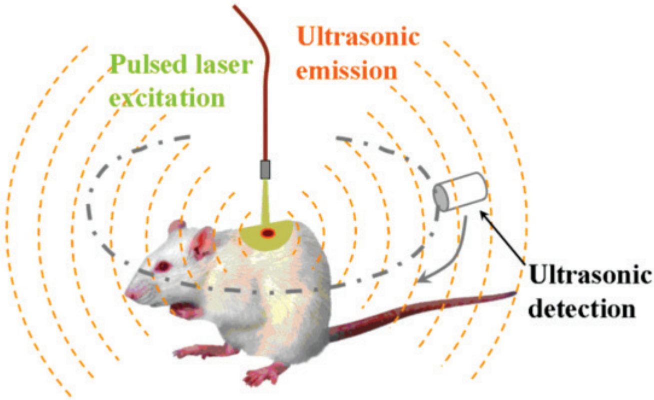
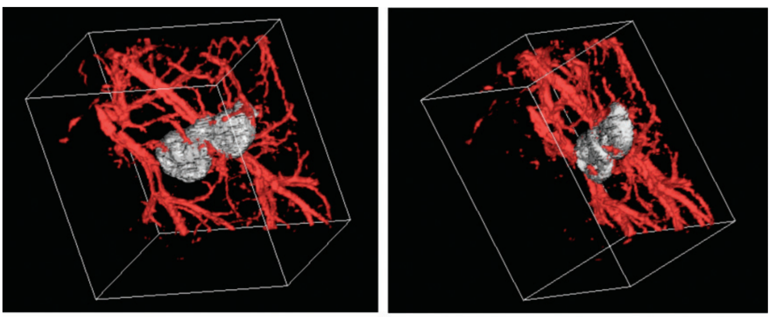


Figure 28 Photoacoustic tomography performed on rat. (http://en.wikipedia.org/wiki/Photoacoustic_imaging_in_biomedicine)



Figue 29 Photoacoustic tomography image of rat brain (http://en.wikipedia.org/wiki/File:Melanoma3DMovie.gif)

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BIOGRAPHY

Azmi Zakaria is a Professor of Applied Optics at the Physics Department, Universiti Putra Malaysia (UPM), Serdang, Selangor Darul Ehsan, Malaysia. He was born in 1954, Pasir Mas, Kelantan and received his early education in his home town and in Kuala Lumpur. For undergraduate study he attended Universiti Kebangsaan Malaysia, received a B.Sc (Hons.) in Physics in 1978, and for postgraduate studies, he received his M.Sc in Optoelectronics from Queen's University of Belfast in 1981 and PhD in Photothermal Physics in 1994 from the University College of Swansea, UK.

Since then he has been teaching in Physics Department, UPM for 32 years until now. He was the Head of Advanced Materials and Nanotechnology Laboratory at Institute of Advanced Technology for three years. For more than ten years he had acted as Chief Students Academic Advisor for Physics Department where it involved administrative as well as advising students in academic and general affairs. He was awarded a 2005 Excellence Award by UPM and has been awarded Certificate of Excellence Service Award by Science Faculty consecutively since 1999.

During his academic career, Prof. Azmi has authored four books, and has published over 140 journal articles and 80 conference proceedings. A few of his articles had been selected to be the top 25 Hottest Articles and his book entitled *Mechanics and Waves* being his major contributions for undergraduate studies on mechanics. For three years since 2005, he was the Chief Editor of Info-Science for Science Faculty.

In his areas of expertise, Applied Optics and Material Science, he has devoted much of his research work in photothermal physics and spectroscopy, solar energy, zinc oxide based varistor and nanomaterials. He has supervised to successful completion of a total of 15 doctoral students and 34 master students. Currently he supervises students at various stages of which six for PhD level, eight for M.Sc level. He has been awarded Faculty's Excellence Scientist Award consecutively since 2003.

Prof. Azmi has been awarded eleven research grants totaling RM1,000,000 to lead and conduct research in photothermal physics and material science, and four research grants with a of total RM600,000 as research collaborator to conduct research in magnetic materials, surface plasmon, solar energy and nitrogen pumped dye laser. He had completed ten research projects and the ongoing researches are *An elucidating study of nanofluids by using photothermal techniques, The Study of Degradation Phenomena of Zinc Oxide Varistor Prepared by Wet Chemical Method,* and *New Transient Converging Thermal Wave Technique*. Previously, at UPM Institute of Advanced Technology (ITMA) he had been acting as Research Program Chief for Alternative and Renewable Energy Laboratory (AREL) for three years from 26th June 2006 and following, he had been promoted to Head for Advanced Material Nanotechnology Laboratory (AMNL) until 31st January 2012, and has been an associate member of the Laboratory until now.

He had involved as a subject matter expert for Open University of Malaysia for physics subject; served as paper reviewer of numerous international and local journals; as an examiner to more than twenty PhD students, fourty Master of Science students; and chairing more than fourty postgraduate examinations. Prof. Azmi had also been involved in conducting low cost laboratory apparatus courses where academics and laboratory staffs of local universities and research institutions learned to develop their own low cost scientific equipments. His professional affiliations include the Optical Society of America (OSA) as a member, and Malaysian Solid State Society (MASS) as a fellow member.

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To All, may Allah SWT bless all of you.

LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
   The Challenge to Communication Research in Extension
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   Indigenous Materials and Technology for Low Cost Housing
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   Changing Roles of Agricultural Economics
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   Marketing Management: Prospects and Challenges for Agriculture
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