4

Developed of a Ceramic-Controlled Piezoelectric of Single Disk for Biomedical Applications

E. Suaste Gómez, J. J. A. Flores Cuautle and C. O. González Morán
Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional
México

1. Introduction

One of the main topical problems that biomedical discipline has the develop of medical equipment, prosthesis, diagnostically and therapy equipment, and the others. In the last field in which the work has been stimulated by the successful develop of methods for monitoring biological signal. Moreover, the aging of the humanity is the key that motivates more research in new instruments for diagnostic and therapy and the investment about new ways to have more information about the state of human health.

The development of new instruments entails the research focuses on new sensors or the improvement of the already existing ones; in this background the called smart materials are the option of choice to develop sensors and instruments based on these materials due to its thermal, mechanical, optical and electrical responses that permits to detect a variety of physics constants and at the same time are characterized for strong structure, a wide range of work frequencies, wide range of temperature operation among others features.

Several studies have been carry out in order to get the optimal material combinations such as the influence of compositionally modified ceramic bodies, or the addition of a variety of elements obtaining a doped ceramics, on the other hand multilayer capacitors, based on smart materials, are base of a variety of studies and are widespread use in the electronic market, having these concepts in mind, a metallic wire was inserted into a ferroelectric ceramic bulk, the wire has more than one propose in the ceramic: using this wire implanted, a free ceramic face is obtained and at the same time the implant provides a free charges that modify ceramic behavior, this face is used in order to measure optic and mechanic events, the wire in total immersion into the ceramic also serve as control electrode and it is named Ceramic controlled piezoelectric (CCP), (Gonzalez & Suaste, 2009).

2. Fabrication

The oxide-mixing route is the most used method for commercial purposes although it has several limitations, like difficulties in achieve microscopic compositional uniformity, is one of the cheaper methods to get ferroelectric ceramics, the method involve the general steps: mixing and grinding, calcinations, grinding, shaping, densification, and finishing, which will be next briefly described (Jaffe, 1971; Moulson, 2003).

Mixing: the raw powders are weighted in an appropriated portion with an allowance for the impurity and moisture content, the grain size is uniformed by grinding usually this part is wet by means of include some liquid to agglutinated the powder.
Calcination: the calcinations purpose is to begin the reaction by the firing the powders at temperatures around 800 – 1100° C depending of the material kind, this step not always is necessary, it depends on the material kind.
Shaping: in this stage the required dimensions and shape are forming by molding the powders and applying pressures that are around 75 - 300 MPa, is in this step that a Pt - wire is put into the middle of the ceramic in transversal way in order to obtain the third electrode.
Densification: also know as firing, it is made in a refractory recipient and at temperatures of 80 to 90 % of material melting temperature in which the constituent ions have the mobility for the solid state sintering process take place.
Finishing: the finishing involves the polishing, machining (if it is necessary), and metalizing.
A ferroelectric PLZT was chosen; this is a $Pb_{1-x}La_x(Zr_{1-y}Ti_y)_{1-x/4}O_3$ ceramic with x = 0.09 and y = 0.35 (PLZT), generally denoted as (9/65/35). This ceramic was produced by the oxide-mixing technique: the raw materials were mixed by ball-milling with an electronic mill (Pulverisette 2, Fritsch) for 20 min; polyvinyl alcohol drops were added with a rate of 1.5 drops per gram of mixture. Powders then were pressed into discs of 10 mm diameter and 2 mm of thickness; the pressure applied was 3,500 Kg/cm^2.
During this process, a Pt-wire of 0.3 mm diameter was implanted in the middle of the ceramic in a transversal way; thus a metallic electrode totally immersed in the ceramic was created. This ceramic was sintered in air with a heater ramp rate of 5 °C/min from room temperature to 600 °C and a second heater ramp rate of 10 °C/min from 600 °C to 1,200 °C; the latter process lasted for one hour in a platinum crucible.
After sinterization, silver electrodes were deposited on the lower face and the Pt-wire of the CCP. Finally the discs were electrically poled, at 1.5 kV/mm for one hour at 60 °C in a silicone oil bath, in order to be used in pulse measurements. The dielectric constant was determined by the capacitance measure. Samples were heated at a rate of 5 °C/min, until 450 °C while the capacitance was measured at 1 kHz with a Beckman LM22A RLC bridge. The dielectric constant was determined by expression (1):

$$\varepsilon = Cl/\varepsilon_0 A \tag{1}$$

where C is the capacitance in F, l is the thickness of the sample in m, A the sample area in m^2 and the vacuum permittivity $\varepsilon_0 = 8.85 \times 10{-}12\ F/m$. The dielectric constant in the CCP was determined with and without the Pt-wire taking the parallel sides as electrodes and is show in Figure 1.
Usually electrodes are taking at parallel sides and Pt-wire is the third electrode however for our applications described in this chapter only will be use one parallel side and Pt-wire as electrodes. The schematic symbol used for describing the CCP can be seen in Figure 2.
The implant as was mentioned earlier provides free charges to the ceramic and at the same time provokes a great ferroelectric domains concentration around it, this domain concentrations results in superior sensibility in the area near to the implant. Figure 3 shows a scheme in which it is possible to see the implant and the domains concentration around it, it also shows the ceramic polarization in areas far from the implant.

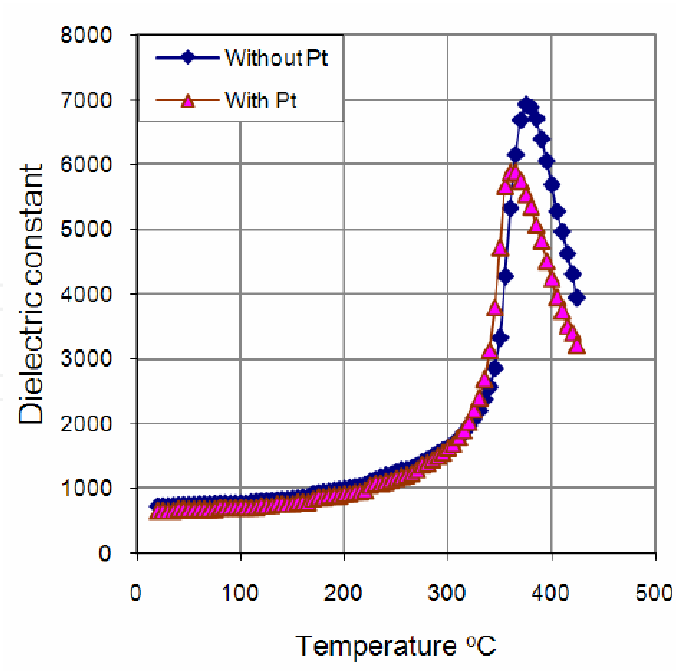


Fig. 1. Dielectric constant piezoelectric ceramic PLZT

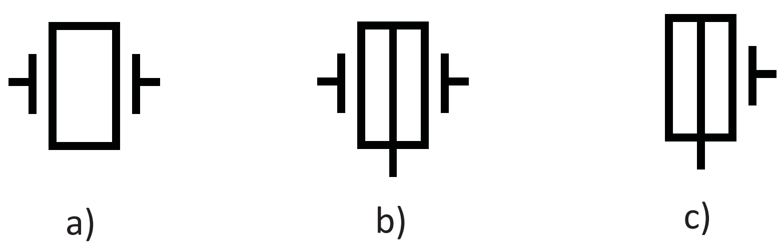


Fig. 2. Graphical symbols that represent reference piezoceramic of PLZT and CCP a) reference piezoceramic with two electrodes, b) CCP, with implant of Pt-wire and two electrodes, c) CCP without an electrode which side face is used like sensor

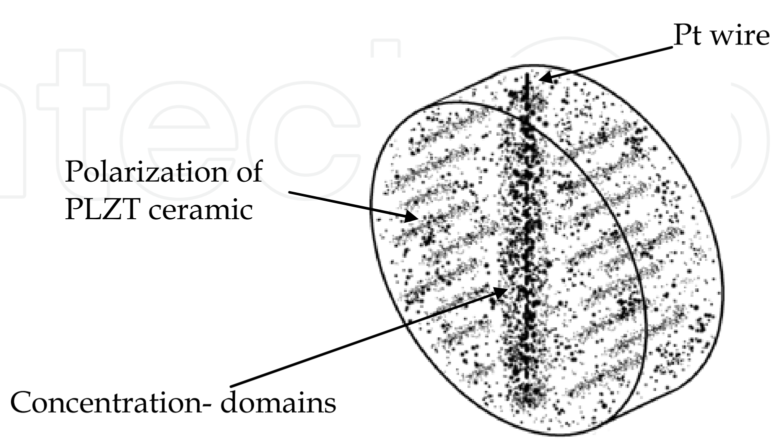


Fig. 3. Scheme from CCP and its domains distributed around Pt-wire.

When the CCP is poled, it originates a great concentration of domains on the Pt-wire because the dipoles are oriented over all its external part. These concentrations achieve free flux charges around the Pt-wire when CCP is excited by stress or light on its side face.

Considering that ferroelectric and piezoelectric materials can be used as sensors and actuators, piezoelectric pressure and acceleration sensors, as well as a variety of piezo-vibrators, are now commercially available. Among piezoelectric ceramics, CCP offers a great variety of applications in medical physics such as the human pulse detection sensor known as PZPG.

In medical physics, micro-circulation of skin blood is a subject of considerable interest due to its role in human metabolism, blood transport from and to the tissue and its role as a liquid coolant of the body in the thermoregulation process.

The measurement of the blood flow is related to the measurement of changes in volume which occur in any part of the body as result from the pulsations of blood with each heartbeat. The instruments that measure volume changes or provide outputs that can be related to them are called plethysmographs. Plethysmographs respond to changes in volume, but there are several devices that in fact measure some other variables related to volume rather than volume itself. One type of these "pseudo-plethysmographs" measures changes in diameter at a certain cross section of a finger, toe, arm, leg or other segment of the body, for example, the non-invasive reflection photoelectric plethysmograph method uses back-scattered optical signals for temporal analysis of skin blood volume pulsations.

Several applications in biomedical area has been developed having as principal component this ceramic with implant such as wireless transmission signals, in which a biological signal is applied to an oscillator by the CCP getting a frequency modulator, in other field CCP is used to obtain cardiac pulse by taking advantage of piezoelectric properties, finally an opacity sensor is an enforce in which is exploited the photoelectric effect that CCP offers, through this chapter these applications will be explained in detail.

Signal modulator

One of the main characteristics that ferroelectrics has is the high dielectric constant, this is due to domains alignment and the susceptibility of material to be polarized when an electric field is applied to the material, a metallic insert into the ceramic provides electric charges and at the same time is a way to modified its behavior (Gutierrez & Suaste, 2009).

Taking advantage of the ceramic high permittivity this ferroelectric sensor (FS) is the base of a frequency modulator, the function is as follows: the traditional electrodes are connected as part of resonance circuit of oscillator and the third electrode is connected to a signal which voltage was increased while the oscillator output was monitoring, a direct relation between control voltage and oscillator frequency was found as Figure 4 shows.

Electrocardiograph signal was also applied to the CCP in the control electrode in order to have a biological signal modulator, the biological signal provokes a difference in the CCP permittivity, as a consequence of this the oscillator output varies proportionally to the signal connected at the control electrode and a modulator frequency was obtained.

The importance of this application is in the wireless field, once the ECG signal is obtained it is only necessary to have an oscillator to modulate the signal, once upon signal was modulated it is necessary a power stage and an antenna in order to have a complete wireless transmitter.

One of the advantages that CCP has is its high ceramic impedance which guarantees the patient electrical isolation; the experimental setup used for this application is show in Figure 5.

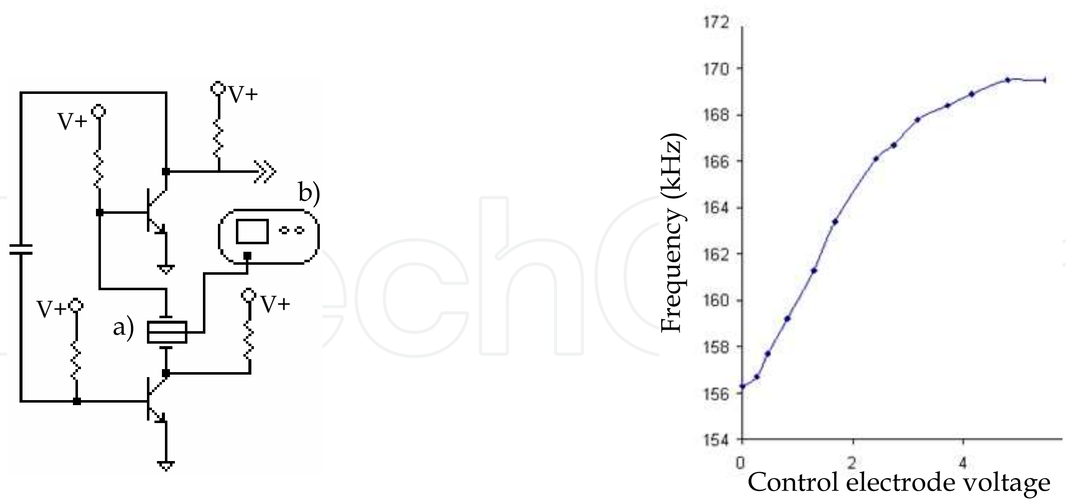


Fig. 4. Left: oscillator with FS in the resonance circuit a) FS b) variable voltage source, right: frequency as function of voltage control electrode

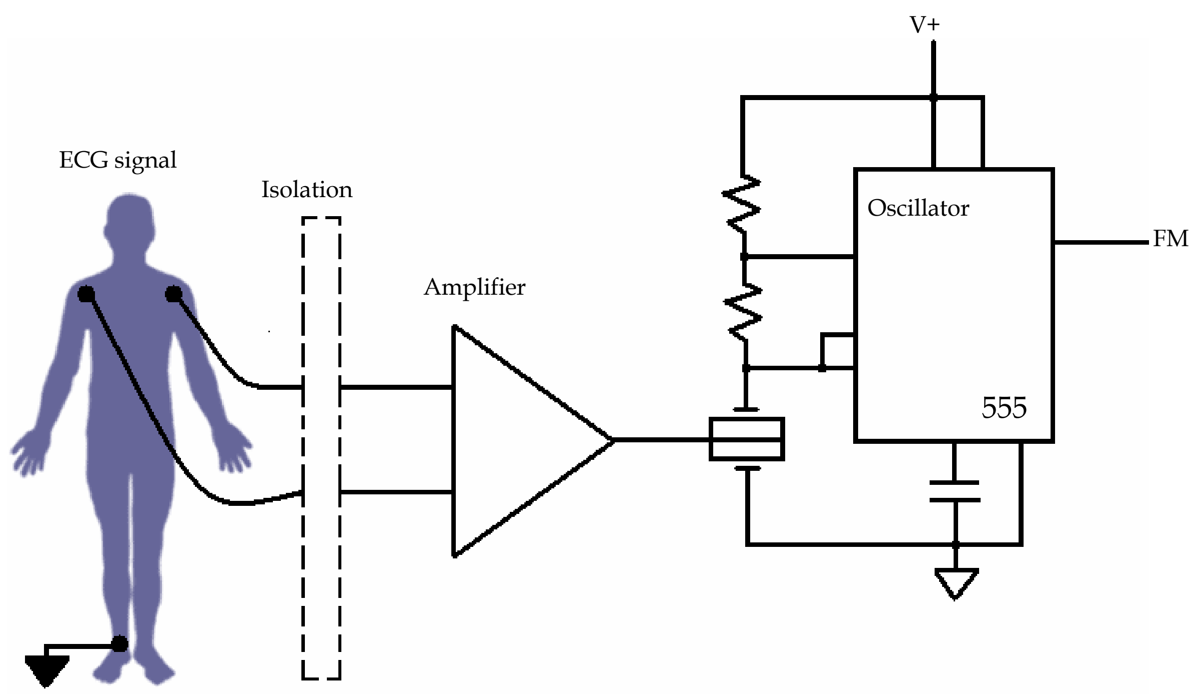


Fig. 5. CCP used as frequency modulator

By the frequency to voltage converter is possible to recover the original signal applied to the ceramic as the same way that in a FM receiver, in Figure 6 can be shown an electrocardiographic signal applied to CCP and a recovered signal after a FM demodulator.

In the Figure 6 is possible to see obtained signal after a frequency demodulator, noise that appearance in the signal is due to the low filter response since the propose of the filter was only to show that is possible to get the original signal, the principals signal characteristics of the original are in the recovered signal.

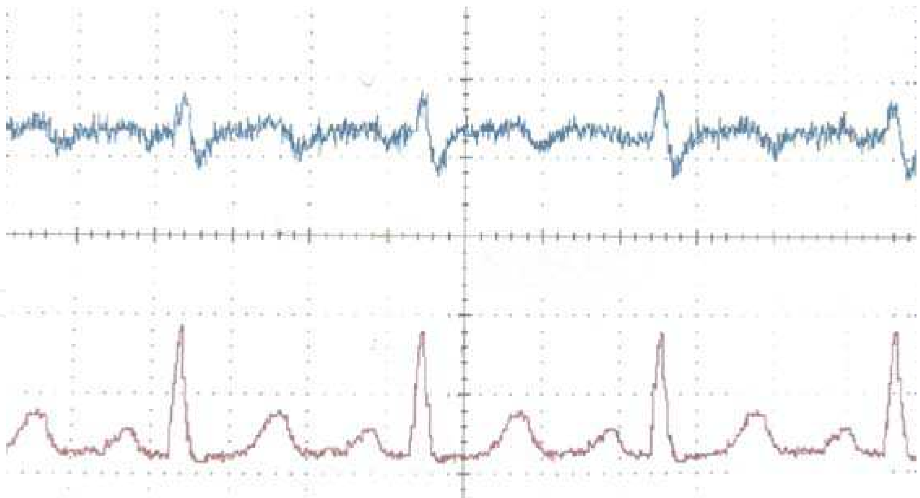


Fig. 6. Above electrocardiographic signal recovered through the frequency to voltage converter after passed to the frequency modulator, down signal applied to the control electrode

Piezo-Plethysmograph

In medical physics, micro-circulation of skin blood is a subject of considerable interest due to its role in human metabolism, blood transport from and to the tissue; it works as a liquid cooler of the body in thermoregulation process. There are several techniques which are used to follow the blood flow in living tissues (Ganong, 2005).

Piezoelectric methods seem to be the most promising for skin microcirculation studies; one advantage of piezoelectric sensors is that they can be used for true dynamic measurements due their wide range of frequency operation. Therefore, the analysis of the skin mechanic pulse piezoelectric detection provides valuable selective information on blood flow on upper skin layers, cutting off the influence of the deeper arteries and veins (Caro, 1978).

The objective of this application is to detect the heartbeat pulses from human beings. The cardiac pulse detection was recorded on an experimental setup. This development also demonstrated the enormous relevance of measuring cardiac pulses at a cross section of the index finger.

Taking advantage of the piezoelectric characteristics of the ceramic a piezo plethysmograph (PZPG) was develop with the CCP, first at all the CCP was submitted to a polarization process by means of apply an electric field of 3 kV by an hour between parallel faces. Control electrode and one face was used to obtain the signal, a free face was used as sense part.

The CCP was mounted onto a finger splint for cardiac signal detection and its signal was amplified. At the same time electro-cardiogram was obtained by means of the use bio amplifier as shown in Figure 7. The measurement of the blood flow is related to the measurement of changes in volume which occur in any part of the body as result from the pulsations of blood with each heartbeat (Suaste et al, 2010).

The CCP showed satisfactory results due to the signal response, in the cardiac monitor graphics ECG and CCP detection that provides additional diagnostic information on the vascular blood flow resistance; the height of the diastolic component of the CCP relates to the amount of the pressure wave reflection, which relates mainly to the tone of small arteries. The timing of the diastolic component relative to the systolic component depends on the pulse wave velocity of the pressure waves in the aorta and the large arteries. This, in

turn, depends on the large artery stiffness. The human vascular system is elastic and multi-branched, and each branching partially reflects back the pressure wave (Janis, 2005).
It was shown that the CCP used as piezoplethismograph has several advantages. It can be adjusted to the fingertip measurements; however, it can also easily be extended by means of spare bands, therefore it is possible to take PZPG measurements from different locations of the body, e.g., forehead, forearm, knee, neck. It is non invasive due to its mechanical detection and there are no chemical reactions with the body or possible current discharges because it is completely isolated and it does not require external electrical supply. The implant is put into the ceramic during the sintering stage, meaning that no additional steps are required, whereas coating the ceramic with a polymer or any other material involves one or more fabrication and characterization steps, which in an industrial process is more expensive. Moreover, this setup eliminates considerable electrical noise.

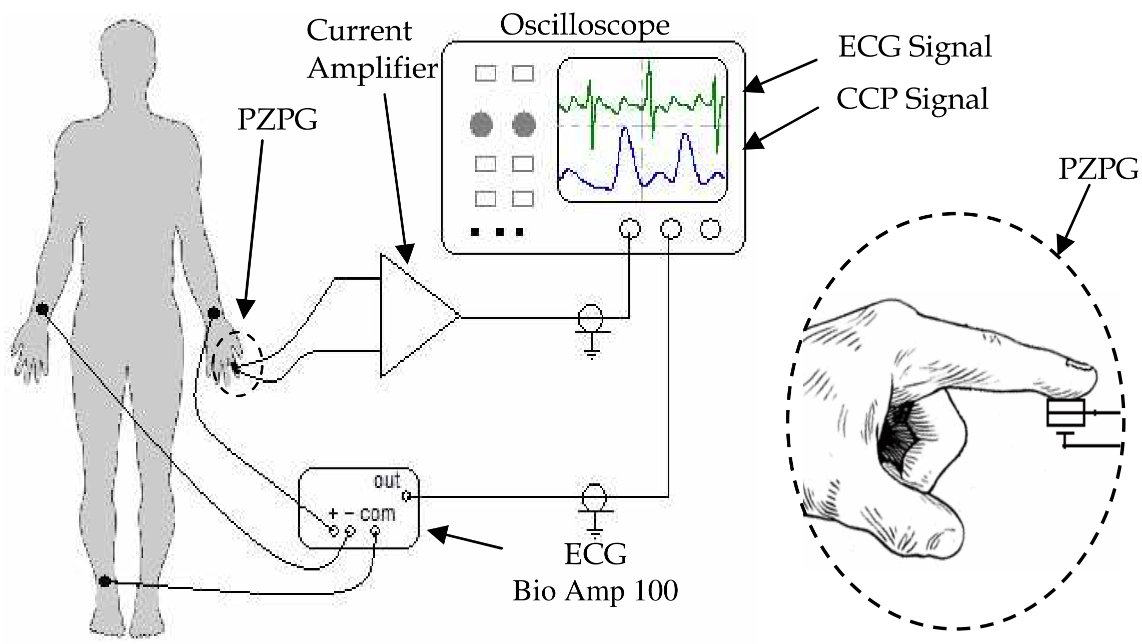


Fig. 7. Experimental setup of Piezopletysmograph in order to obtain fingertip pulses

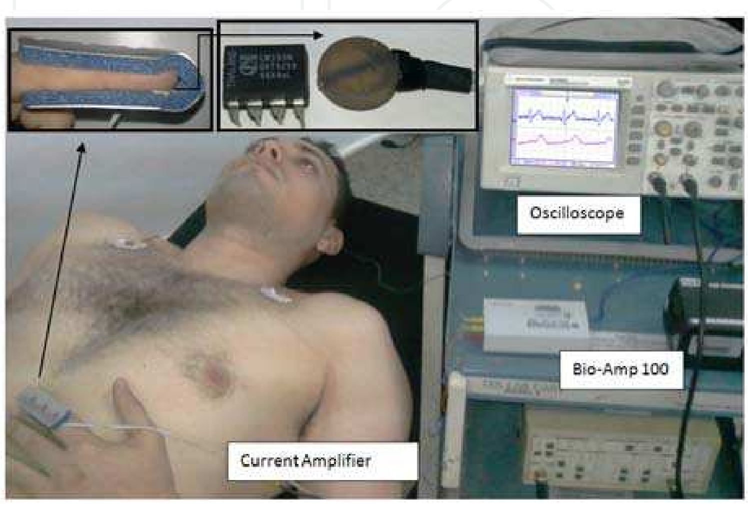


Fig. 8. Real setup used for get fingetip pulses

By the use of a system of data acquisition the cardiac pulses signal can be recorded, analyzed and compared with electrical registry of the heart (Gonzalez et al, 2010). The system of acquisition of pulse shows in a computer screen a friendly atmosphere to us that can be adapted to diverse situations of measurement, as Figure 9 shows.

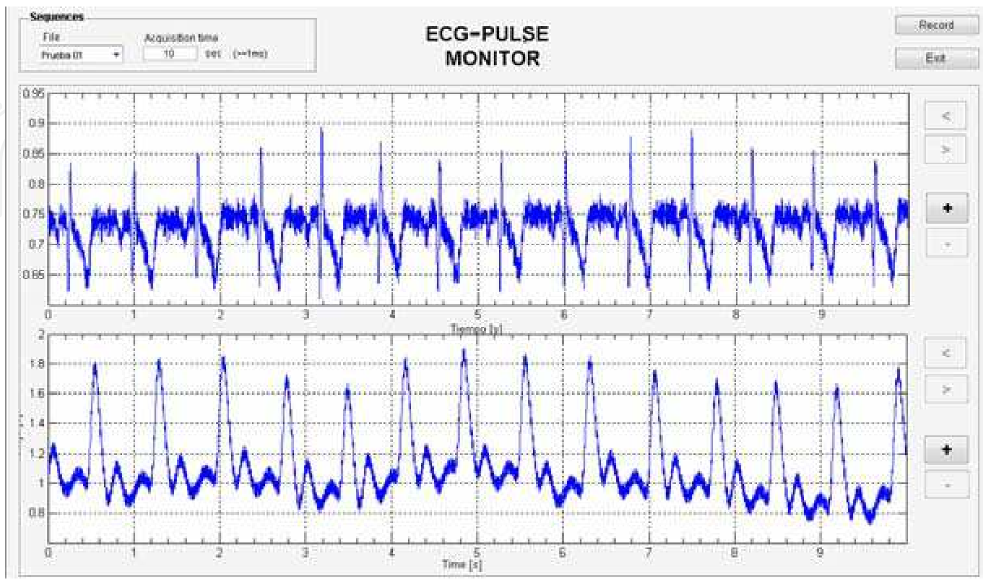


Fig. 9. Screen of acquire system captured from a computer, above ECG register, down cardiac pulse acquire with CCP

In figure 10 it is possible to see an amplified ECG and PZPG curves

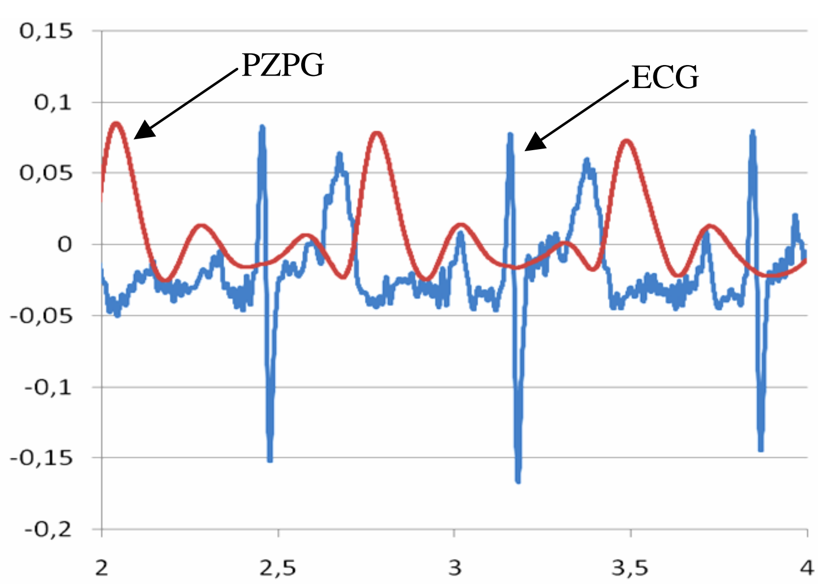


Fig. 10. PZPG and ECG curves response

The timing of the diastolic component and the reflections, according to the place of measure, can be determined with the PZPG.
With this experimental setup is possible to get a fast way to analyze cardiac frequency variability since the frequency spectrum getting by the data acquisition system is the same for both signal ECG register and PZPG signal.

Results demonstrated that the PLZT bulk with Pt-wire has the following advantages: the increase in surface analysis is superior due to the Pt-wire, which works as a third electrode; the proposed CCP can be used at much higher temperatures than the conventional Si based sensors; the CCP is easy to make and the size of this bulk material can be modified; finally, the CCP offers good versatility as a mechanical sensor due to its ferroelectricity.

Opacity sensor

There are several kinds of ferroelectric materials that exhibit photovoltaic effects under near-ultraviolet light even temperature changes. When the material is illuminated after poling, voltage and current can be generated due to the separation of photo induced electron and holes caused by its internal electric field. This is considered an optical property of the material itself which has potential applications for supplying energy transfer in microelectromechanical systems and optoelectronic devices (Sturman & Fridkin, 1992; Ichiki et al, 2004).

The steady current in the absence of applied voltage, called photocurrent, is considered the result of photo carriers and the asymmetric electromotive force induced by near-ultraviolet radiation (Tonooka et al, 1998). Therefore, photocurrent is a very important parameter for optical detection (Qin et al, 2007). In this field photovoltaic current permits to get a signal related with the light that pass thought the translucent sample getting with this opacity detector.

In this use a translucent sample is put on the free ceramic face named opacity sensor (OPS) whilea frequency modulated light beam is applied, the obtained signal is analyzed and photovoltaic current related with the sample opacity is obtained the signal getting without sample is considered as 100% and the signal with sample which diminish by the sample opacity and thickness is related as a percentage, Figure 11 shows the experimental setup used for this application. (Ichiki et al, 2005; Ichiki et al, 2006; Suaste et al, 2009).

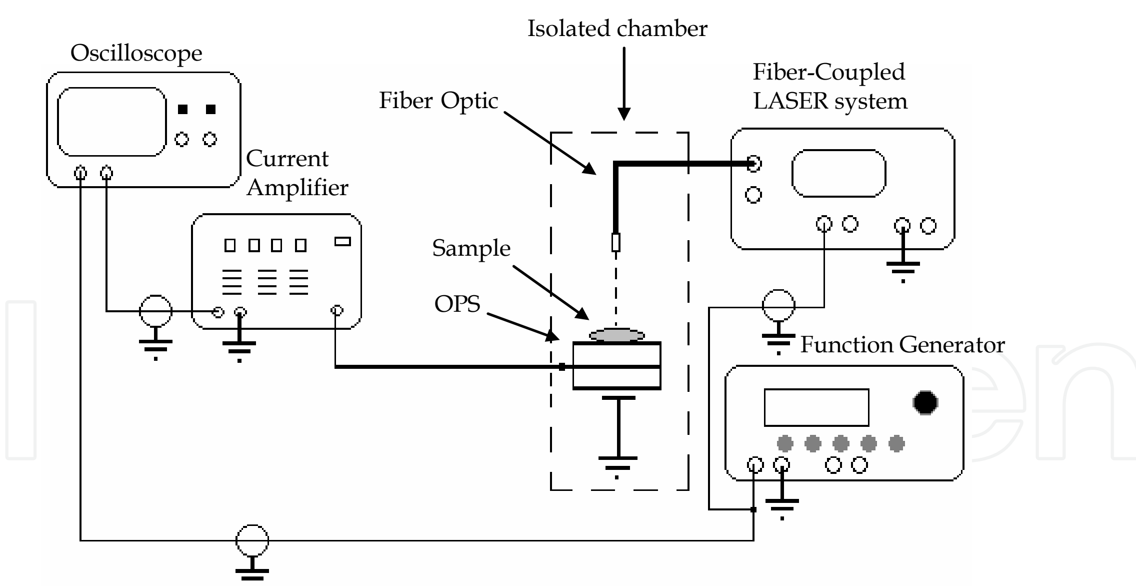


Fig. 11. Experimental setup for opacity measure

Since the CCP has not plane response curve it is necessary to get its characteristic curve in order to have a reference curve that help us to normalize the response, Figure 12 shows the CCP response without sample.

Some samples such as fruit tissues, vegetal oils and other thin materials were tested by this sensor Table 1 shows the materials and its thickness, the resultant curves are shown in Figure 13, the OPS curve is the result from stimulate sensor without sample.

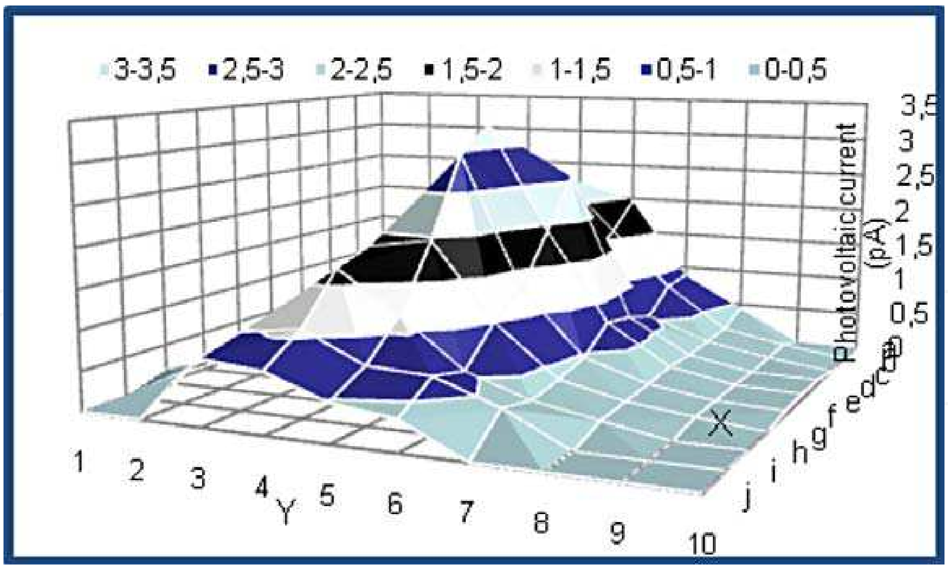


Fig. 12. CCP curve response without sample when is stimulated 160 mW/cm² of LASER illumination

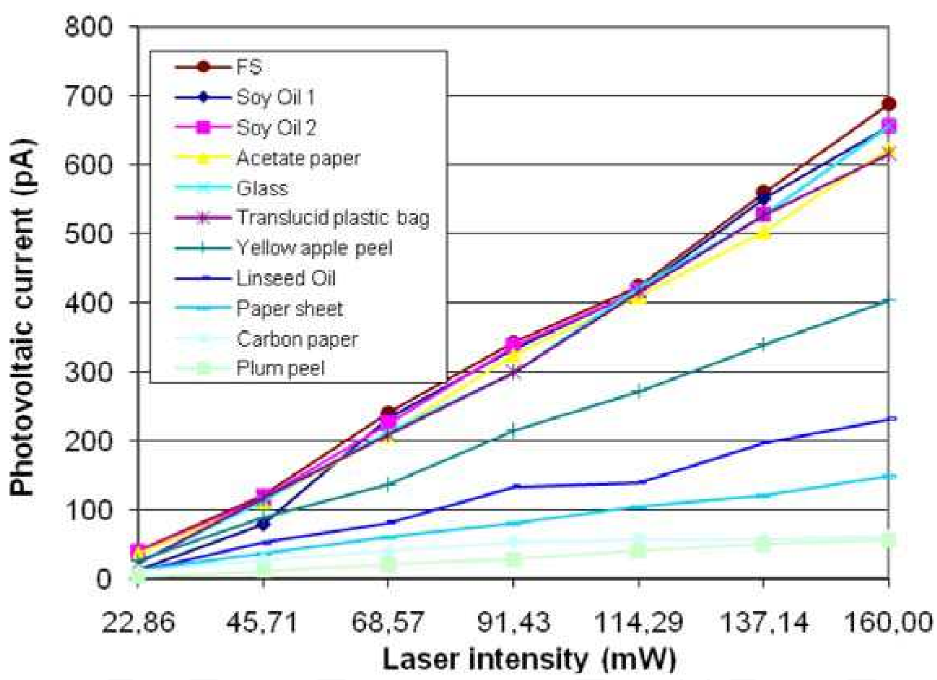


Fig. 13. CCP detected curves from different liquids and thin solids

By the use of an x-y, the ferroelectric sensor implanted allows to perform 2D scanning and generate 3D graphics or images of opacity depending on the percentage of opacity of the sample in the bi-dimensional setup coordinate system that could have novel applications such as before transplant 2-D cornea scan in order to verify its opacity, 2-D scan opacity of insects (Entomology), etc (Matusik et al, 2002; Chamberlain, 2008; Dekking, 1948), the experimental setup is showed in Figure 14.

By the use of X-Y positioning platform images about different opacity regions can be obtained. In Figure 15 it is possible to see a 3D graphic taken at a plant leaf (Myrtus communis).

Liquids and thin materials samples measured on OPS	Thickness (μm)	% of Opacity
Plum peel	76.2	91.7
Carbon paper	36.56	84.33
Paper sheet	101.6	76.61
Linseed Oil	100	60.82
Yellow apple peel	88.9	36.84
Transparent Plastic Bag	63.5	12.28
Glass	152.4	12.28
Acetate paper	109.22	5.26
Soy Oil 2	100	1.17
Soy Oil 1	100	2.92

Table 1. Opacity percentage of different liquids and thin materials at 91.43 mW/cm^2 of illumination using one-dimensional setup

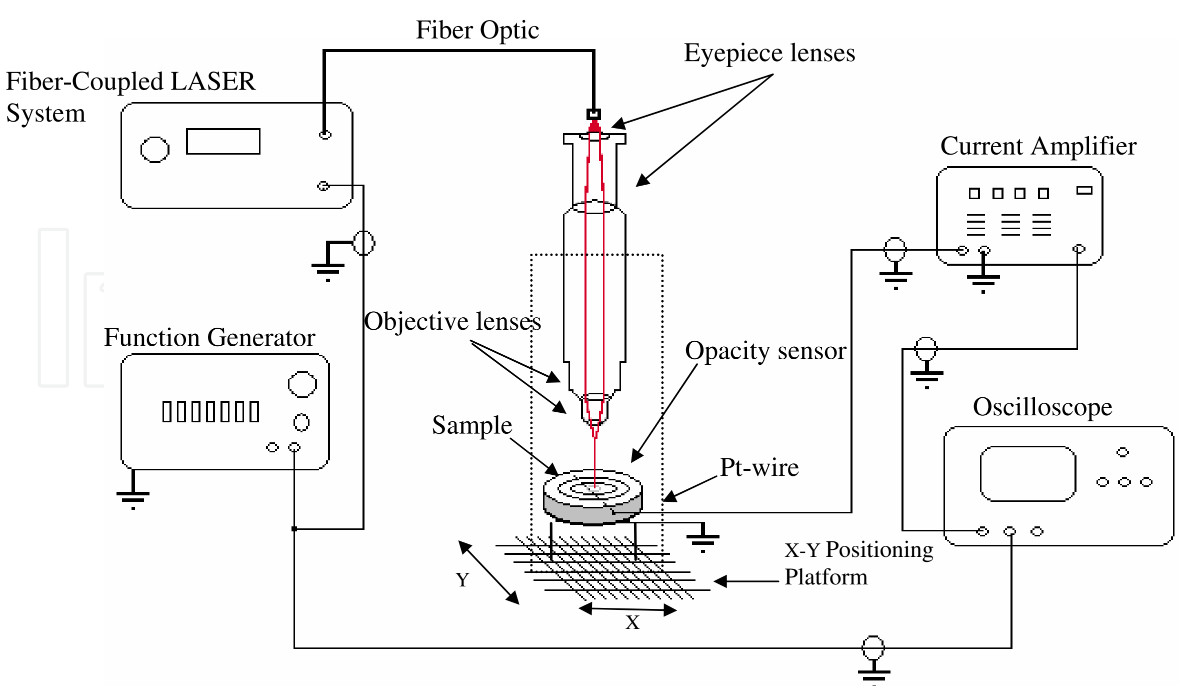


Fig. 14. Experimental setup used as 2D opacity scan

Quantitative sensitivity comparison with other types of opacity/transmission would be relative due to the chemical compositions of each sensor and because finally whatever the type of sensor, they only give a percentage measure parameter. The most significant differences among ferroelectric sensors and Si based sensors are: 1) Si based sensors require electrical external supply and do not have domains; in contrast ferroelectric sensors do not require an external electrical supply; 2) the Si based sensors have greater sensitivity than ferroelectric sensors but these last offer a good response at extreme temperatures, up to 570^{o}C according to its chemical composition (ferroelectric phase transition) (Jona & Shirane, 1993).

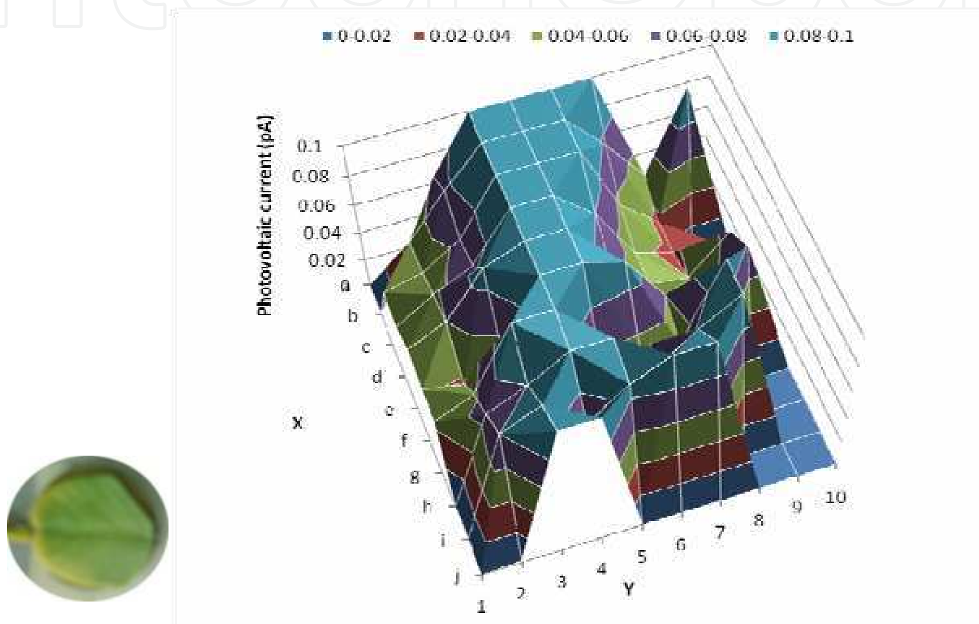


Fig. 15. CCP response with a plant leaf

3. Conclusions

The CCP device demonstrated a good performance in optic and mechanic probes as an opacity sensor and cardiac pulse measurement device, respectively. A study with several people in order to determine the study basis such as blood pressure detection, cardiac pulse in different zones of the body, continuous cardiac pulse, and the associated cardiac variability with electrocardiogram data are in current stage.

The CCP has an interesting configuration because by the one hand it provides a great ceramic insulator that does not affect human beings and on the other hand it is very significant that this sensor was developed not only for this mechanical field of study, but also has multiple applications in different areas, for example: optics, acoustics, electrical and chemical sensing. Finally is important to mention that an advantage of an implanted ceramic over a conventional ceramic (with two parallel conductive layers) is the increase of a mechanical and optical signal measured due the physical reduction (cutting the piece) making minisensors for multiple uses such as neonatal applications

Finally, the CCP recently developed such as is described in this chapter, offers a window of opportunity to the development, the circumstances are right for working not only in biomedical engineering but also in diverse fields of applied research as the examples showed.

4. References

Caro C. (1978). *The mechanics of the circulation*, Oxford University Press, 0192633236, NY-Toronto

Chamberlain, D. (2008). The transmission opacity tester. Paper Technology, Vol. 49, pp. 42-4, 0 306-252X

Dekking, H. M. (1948). Opacity meter for cornea and lens. *Ophthalmologica*, Vol. 115(4), 4, 219-226

Ganong, W. F., (2005). *Review of Medical Physiology*, McGraw-Hill Medical, New York

González-Morán C. O., Suaste-Gómez E. (2009). Developed and experimental evidence of a ceramic-controlled piezoelectric bulk implanted with Pt wire based on PLZT, *Ferroelectrics,* Vol. 392, 98-106, 0015-0193

González-Morán C. O., Flores-Cuautle J. J. A. and Suaste-Gómez E. (2010). A Piezoelectric Plethysmograph Sensor Based on a Pt Wire Implanted Lead Lanthanum Zirconate Titanate Bulk Ceramic, Sensors 2010, Vol. 10, 7146-7156

Gutierrez-Begovich, D.A.; Suaste-Gomez, E., Frequency modulation via a biological signal using a controlled piezoelectric ceramic, *Proceedings of Pan American Health Care Exchanges 2009,* pp.7-7, 978-1-4244-3668-2, México City, March 2009

Ichiki M. et al. (2006). Photovoltaic Effect of Crystalline-Oriented Lead Lanthanum Zirconate Titanate in Layered Film Structure, Vol. 45, No. 12, 9115-9118,

Ichiki M., Maeda R., Morikawa Y., Mabune Y. and Nakada T., (2004). Photovoltaic effect of lead lanthanum zirconate titanate in a layered film structure design, *Appl. Phys. Lett*., Vol. 84, pp. 395-397, 0003-6951

Ichiki M., Maeda R., Morikawa Y., Mabune Y., Nakada T. and Nonaka K. (2005). Preparation and Photovoltaic Properties of Lead Lanthanum Zirconate Titanate in Design of Multilayers, *Japanese Journal Appl. Phys.*, Vol. 44, 6927-6933, 0021-4922

Jaffe B., Cook W. R. (1971). *Piezoelectric Ceramics*, Academic Press, 0-12-379550-8, London and New York

Janis, S. Optical Non-Invasive Monitoring of skin Blood Pulsations. Appl. Opt. 2005, 44, 8

Jona F., Shirane G. (1993). Ferroelectric crystals, Oxford, 0-486-67386-3, New York

Matusik, W; Pfister, H; Ngan, A, et al. (2002). Image-based 3D photography using opacity hulls, ACM Transactions on graphics, Vol. 21 Issue 3, 427-437, 0730-0301

Moulson A. J., Herbert J. M. (2003). Electroceramics, John Wiley & Sons, 0471 49748 7, England

Qin M., Yao K., Liang Y. C., Shannigrahi S. (2007). Thickness effects on photoinduced current in ferroelectric $(Pb_{0.97}La_{0.03})(Zr_{0.52}Ti_{0.48})O_3$ thin films, *Journal of Applied Physics*, Vol. 101, 014104-1 014104-4, 0021-8979

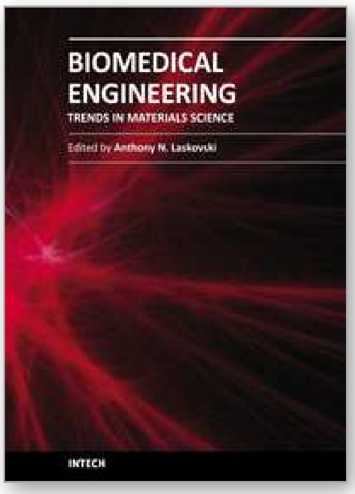
Sturman B. I. and Fridkin V. M. (1992). *The Photovoltaic and Photorefractive Effects in Noncentrossymetric Materials Vol. 8*, Gordon and Breach Science Publishers, 288124498X, New Jersey

Suaste-Gómez E., González-Morán C. O. (2009). Photovoltaic Effect of Lead-Free Piezoelectric Ceramics, (Bi0.5Na0.5)0.935Ba0.065TiO3 and Pb0.88(Ln)0.08Ti0.98Mn0.02O3 (Ln = La, Eu), Ferroelectrics, Vol. 386, 70-76, 0015-0193

Suaste-Gómez E., González-Morán C. O. and Flores-Cuautle J. J. A. (2009). Developed and applications of a novel ceramic-controlled piezoelectric due to an implant of Pt-wire into the body of sigle disk of $BaTiO_3$ ceramic, *Proceedings of WC2009, IFMBE 25/XII,* pp. 89-92,", O. Dössel and W. C. Schlegel, 978-3-642-03892-1, Munich, Germany

Suaste-Gómez E., Flores-Cuautle J. J. A., Gónzalez-Morán C. O. (2010). Opacity Sensor Based on Photovoltaic Effect of Ferroelectric PLZT Ceramic With Pt Wire Implant, *Sensors Journal, IEEE* , vol.10, no.6, 1056-1060, 1530-437X

Tonooka K., Poosanaas P. and Uchino K. (1998). Mechanism of the bulk photovoltaic effect of ferroelectrics, *Proceedings of SPIE Volume: 3324,* 9780819427687



Biomedical Engineering, Trends in Materials Science
Edited by Mr Anthony Laskovski

ISBN 978-953-307-513-6
Hard cover, 564 pages
Publisher InTech
Published online 08, January, 2011
Published in print edition January, 2011

Rapid technological developments in the last century have brought the field of biomedical engineering into a totally new realm. Breakthroughs in materials science, imaging, electronics and, more recently, the information age have improved our understanding of the human body. As a result, the field of biomedical engineering is thriving, with innovations that aim to improve the quality and reduce the cost of medical care. This book is the second in a series of three that will present recent trends in biomedical engineering, with a particular focus on materials science in biomedical engineering, including developments in alloys, nanomaterials and polymer technologies.