Chapter

# The Advent of Application Specific Integrated Circuits (ASIC)-MEMS within the Medical System

*Jian-Chiun Liou*

## Abstract

Medical healthcare has become one of the fastest growing and largest industries in the world. More and more people are aware of the precious and important life. At the same time, personal disposable income increases and awareness of disease prevention increases. It allows the healthcare industry to maintain high growth rates. Micro-electro- mechanical systems (MEMS) is one of the most revolutionary semiconductor components. The advent of Application Specific Integrated Circuits (ASIC)-MEMS has created a new era for the healthcare industry. The medical Micro LED detects the blood vessel position with the emission light source and repositions the blood flow state of the blood vessel. Micro LED mainly uses the MEMS micro-fabrication technology to micronize, array, and thin film the traditional LED crystal film. This article will explore how to use MEMS wafers to redefine the needs of the healthcare market and open up new growth opportunities for healthcare applications. With the shift from first-hand medical devices from the hospital business to personal use, miniaturization, economics, reliability and battery life have become new demands in the healthcare market.

**Keywords:** ASIC, MEMS, medical system

## 1. Introduction

Biometric technology has freed people from cumbersome passwords and cluttered IC cards. Among them, the finger vein identification technology is also referred to by the industry as the world's top biometric identification technology. Its misrecognition rate was only 0.0001%, far below the 0.001% of the fingerprint and 1.3% of the face. Although fingerprint recognition technology and face recognition are developing rapidly, there are some flaws [1–12].

In addition to the identification technology itself needs to be improved, some problems that are difficult to avoid, such as being affected by human body temperature. Some unexpected situations such as peeling, injury, etc. will affect the ability to identify. In this case, finger vein recognition technology came into being. It is referred to by the industry as the world's top biometric technology. It is understood that fingerprint, face, iris and other identity recognition systems are good. However, there are still some technical loopholes. As long as it fingerprints its own fingerprints, it allows others to punch cards. Furthermore, if a fugitive turns his face through plastic surgery, then the security measures for customs, airports, and other public places will be like dummy. In addition, iris recognition technology is extremely accurate. However, it is powerless for patients with blind or eye diseases. In addition, iris recognition technology requires expensive cameras for image acquisition, which is costly and difficult to use in a wide range of applications. In Asia, iris recognition technology is difficult to promote. Another important factor is that the technology is very difficult to identify with dark eyes. The sound will have a big contrast with usual. At this point, the voice recognition system is likely to be misjudged or unrecognizable. As a "live recognition" technology, finger vein recognition is via a finger vein identifier. It obtains individual finger vein maps, stores characteristic values, and then matches them for personal identification. The basic principle is to use the red blood cells in veins to absorb this characteristic of specific near-infrared rays. The finger is irradiated with near-infrared light, and the light transmitted by the finger is sensed by an image sensor. It acquires the vein image inside the finger to perform biometric identification. The key is the hemoglobin in the erythrocytes flowing through the veins. It absorbs near-infrared rays near the wavelength of 700–1000 nm. It causes less transmission of near-infrared rays in the vein portion. When near-infrared light is transmitted, the veins are highlighted on the image sensed by the image sensor. The muscles, bones, and other parts of the fingers are weakened. This gives clear images of veins. Finger vein recognition technology uses the texture of the finger veins for authentication. It is harmless to the human body, and it is not easily stolen or forged [13–19].

In 1993, scholars Allen and Murray used an Artificial Neural Network (ANN) algorithm to classify PPG waveform shapes (SI) in patients with foot lesions. The results showed a 90% accuracy and the degree of vascular lesions in the lower extremities could be identified [20–25]. In 2008, scholars Allen et al. combined the correlation between ECG waveforms and the PPG waveforms of the temporal limbs of the lower extremities, and proposed quantification of the number of parameters used as the basis for the degree of vascular lesions [26–28].

The human body itself is a chemical sensor and has a variety of chemical sensing functions. It includes taste, smell, hormonal receptors of the endocrine system, neurochemical transmission materials of the nerve conduction system, and the like.

Chemosensory devices are bio-technical methods for obtaining bioactive molecules in the human body. It enables chemical reactions with molecular recognition materials of specific substances. It converts this reaction into an electronic signal via a converter and outputs graphic information to medical personnel for interpretation. For example, respiratory testing, immunological testing, genetic screening, drug tracking, etc. are all commonly used chemical sensing methods. Its main sensing biochemical parameters include: respiratory gas composition, blood, blood glucose, pH, and chromatography. BioMEMS covers biotechnology, nanomaterials, and MEMS integration technologies. In addition to the general miniaturization of biomedical testing instruments, it also contributes to the development of smaller, lower power implantable biomedical sensors. It allows patients with chronic conditions that require long-term physiological monitoring to be used more comfortably and conveniently.

Moreover, it utilizes a microelectromechanical process compatible with complementary metal oxide semiconductors (CMOS). BioMEMS integrates sophisticated application IC circuits and RF chips. It not only improves product functionality, but also transmits and analyzes biomedical test data. It is conducive to the establishment of a complete medical information network, or even to achieve remote care services [29–31]. In this study, the medical Micro LED scans the blood vessel position with the emission light source and repositions the blood flow state of the blood vessel. This study included system design, Micro LED arrays combined with CMOS processes, and post-assembly assembly measurements.

## 2. Architecture

BioMEMS biomedical sensors are mainly using microelectronics technology to miniaturize large-scale detection instruments. The sensor's architecture combines microelectronics, microfluidics, and biodetection technologies. It is used with physical or chemical converters to convert biochemical parameters into electronic signals. Finally, digital output is used to present relevant detection information in graphic form. It is provided to users (biochemical researchers, medical professionals, patients or their families, etc.) for interpretation. The physical sensor is mainly a measure of the physical characteristics of the body itself. The sensing parameters include: size or shape change, force/force distance value, speed/acceleration, temperature, pressure, and flow. It applies these physical parameters to design a BioMEMS sensor that can sense changes in subtle physical quantities. It measures body reactions such as muscle contraction, blood pressure, body temperature, blood flow rate, electrocardiogram, and vision.

The medical Micro LED scans the blood vessel position with the emission light source and repositions the blood flow state of the blood vessel. Micro LED mainly uses the MEMS micro-fabrication technology to micronize, array, and thin film the traditional LED crystal film. It uses a large amount of transfer technology to mass transfer the crystalline film to the circuit board. It uses physical deposition to make the protective layer and finally completes the package. Among them, the key core technologies mainly include two steps: the micro-processing technology and the massive transfer technology.

Inductively Coupled Plasma Ion Etching (ICP) was used on the epitaxial thin film layer of the LED. It directly forms a micron-sized Micro LED epitaxial thin film structure. The fixed pitch of this structure is the required pitch for displaying the pixels. It bonds the LED wafer (including the epitaxial layer and the substrate) directly to the driver circuit substrate, and finally peels the substrate using a physical or chemical mechanism. It only has 4–5 μm Micro LED epitaxial thin film structure on the drive circuit substrate to form display pixels.

a. Define a pattern of metal bumps using photo resists in the open area of the exposed SiNx dielectric protection layer. It produces fine pitch In bumps with thermal evaporation squares. Subsequently, the FC-150 die bonder was used to thermo-bond the LED die onto the CMOS substrate, followed by an under-fill to fix the micro-die array.

b. The native GaAs substrate of the red LED is removed by wet etching. It uses an ammonia aqueous solution ($NH_4OH{:}H_2O_2$ = 1:10) soaked at 50° for 30 minutes to remove the GaAs substrate. All active 192 × 64 LED microchip array device manufacturing processes have been completed. The structure of the micro-chip LED array device is shown in **Figure 1**.

The purpose of pulling the common N metal electrode with a redistribution layer to the same height as the area of the Micro LED Pixel is to improve the contact yield of the In bump bonding-induced CMOS substrate. In biomedical applications, optical/optical chemical sensors using optical principles are common methods in the field of biology. It uses the biomedical detection method of the optical principle. It mainly utilizes the self-luminous effect of the biomolecule itself or the extra light

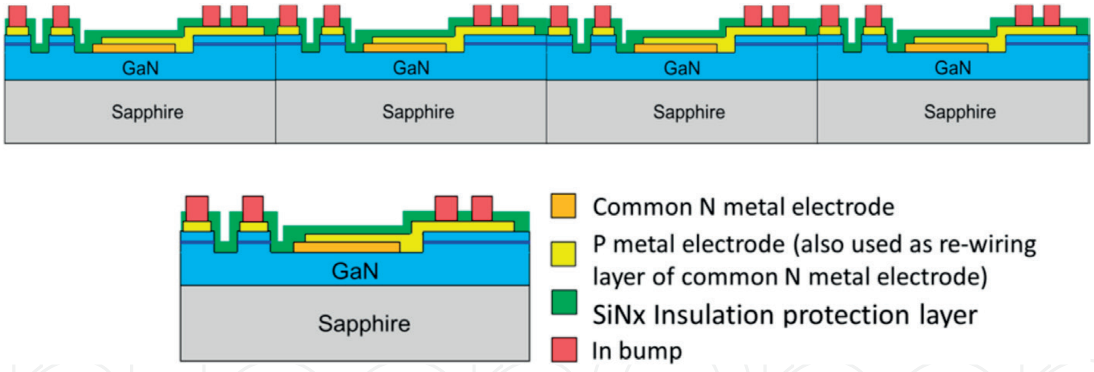


**Figure 1.**
*Blue and green light resolution 192 × 64, pixel cycle 19.2 μm linear arrangement of micro-crystals LED array element schematic diagram.*

effect induced by the extraneous molecule, so that the optical signal is obtained and the quantitative optical measurement method is used. It tests the various optical signals that have been obtained. This method is also conducive to detection under an optical microscope. Spectral analysis is a common detection method for optical/optical chemical sensors. Spectral analysis is a non-destructive, real-time detection technique with a wide spectral range. It is not disturbed by electrical noise. Therefore, multiple parameters can be detected at the same time. It has the advantages of being quick, simple and accurate. BioMEMS Cooperates with ICT technology; it uses BioMEMS sensors made by MEMS technology. In addition to its small size, it is easy to integrate with integrated circuits. It has the advantages of high integration in related biomedical detection digital signal processors (DSPs), analog/digital conversion chips and other circuits. Therefore, in data acquisition and calculation, it can have a higher resolution than previous detection instruments and can process multiple data at the same time. CMOS improves integration, microcomputer-based sensors for biomedical applications have been introduced into the CMOS standard process to help integrate biosensing devices with related measurement circuits. It can further integrate heterogeneous circuits such as RF chip, biomedical detection DSP, and analog/digital conversion chip in System in Package (SiP) mode. Sensors can include multi-applications such as specimen import/export, specimen sensing, signal interpretation, data storage, wireless transmission, and instant exception alerts. In addition, BioMEMS biomedical sensors can be manufactured in large quantities through CMOS standardization processes. Significantly reduce production costs, in addition to help in some detection applications. It can produce disposable products to reduce the risk of cross-contamination of specimens. Increased efficiency/accuracy, in clinical applications, especially in dealing with various acute and chronic diseases, it measures the changes of various biomedical detection signals in the physiological system in real time. It is often the decision-making basis for diagnosis and treatment. BioMEMS sensors constructed using MEMS technology. With the development of digitalization, its sensors can quickly perform functions such as sensory sensing, data storage, and abnormal warning. In addition to providing more information for professional judgment, it can conduct continuous monitoring and data comparison. It helps the medical staff to detect abnormal reactions of the patient as soon as possible so that appropriate medical action can be taken immediately.

The miniaturization of BioMEMS allows the device to be worn or implanted in the body to enable continuous monitoring and comprehensive prevention. It immediately provides the patient's physiological condition to the medical staff, enabling the patient's condition to be diagnosed and treated promptly. Furthermore, medical staff can also help improve the lifestyle of the patient in view of the accumulated

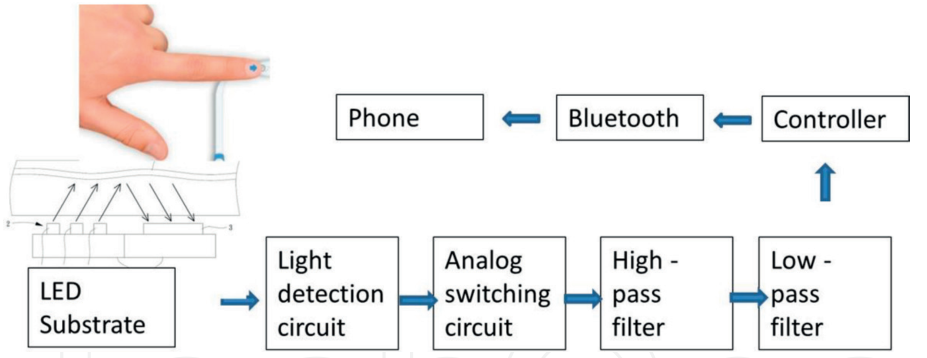


**Figure 2.**
*The application specific integrated circuits (ASIC)-MEMS within the medical system.*

information. The wireless transmission accelerates data updates and uses wireless technology to transmit detection data for various care devices such as thermometers, scales, sphygmomanometers, blood glucose detectors, and electrocardiograms. It is applied to medical examinations in general medical institutions. It can achieve real-time data consolidation and instant medical diagnostic operations. **Figure 2** is the application specific integrated circuits (ASIC)-MEMS within the medical system.

Infrared light has strong penetrating power on human skin and subcutaneous tissue. External effects of infrared radiation on the human body can increase the temperature of skin and subcutaneous tissue. It promotes blood circulation and metabolism and promotes human health.

Infrared physiotherapy has been confirmed clinically for the thermal effects, anti-inflammatory effects and regeneration of tissue. It is usually treated with direct irradiation of the lesion.

Near-infrared micro-irradiation therapy has a significant improvement in microcirculation. Especially in the micro-flow state improved significantly. The performance of the capillary blood flow after irradiation was accelerated, and the red blood cell aggregation was reduced. The phenomenon of hyperemia in the inferior venous plexus of the finger decreases or disappears. Therefore, it has a positive effect on improving the nutrition, metabolism, repair and function of body tissues and important organs. The mechanism by which infrared light produces secondary effects on the human body is not yet fully understood. The frequency of sound waves is higher than 20,000 Hz, which is called “ultrasonics”. Ultrasonic mechanical vibration is used in medical treatment and is called “ultrasonic treatment”. The medical behavior of implanting organisms with ultrasonic energy is “supersonic free penetration therapy.” Ultrasound diagnosis uses ultrasound as a part of the biological scan to detect pathological changes. Ultrasonic waves can also be mixed with other different currents if needed. It not only can easily detect the sensing area of the tissue of the birth object, but also can be used for fixed-point treatment.

## 3. Fabrication

In this study, blue-green, red-colored and red-colored LED epitaxial wafers were used for the process development of micro-chip LED array elements. The process-related steps were as follows: the optimization process was developed, and the process steps were described briefly.

1. Blue and green GaN-based microchip LED array device manufacturing process:

a. Defining the P-type metal contact electrode area on the surface of the P-type semiconductor layer with a photoresist using a yellow lithography process. It uses an E-beam evaporator to deposit 225 nm thick indium tin oxide ITO as a P-type ohmic contact metal. The characteristic resistance value of about 1E-2 Ω-$cm^2$ can be obtained after 1 minute treatment at an annealing temperature of 600°C. P-type ohmic contact metal on the blue and green light surface of the wafer is formed with photoresist on it to define the microchip LED Mesa platform pattern. It uses RIE to etch the photoresist pattern and transfer it to the surface of the blue and green light-emitting wafers. After removing the excess photoresist layer, the active layer of the well is exposed to the N-type semiconductor layer to complete the Mesa platform definition. The etching depth is about 0.8 μm.

b. Define an N-type metal contact electrode pattern with photoresist on the N-type semiconductor layer exposed by the etching. It uses an E-beam evaporator to deposit approximately 500 nm of titanium/gold (Ti/Au = 2000 Å/3000 Å) as an N-type ohmic contact metal electrode with a characteristic resistance of 1E-4 Ω-$cm^2$.

c. SiNx dielectric protection layer grown 300° PECVD with a thickness of 0.3 μm to ensure the position of the indium ball when indium bumps are reflowed into indium balls. It uses a photoresist on the SiNx to define the dielectric protection layer opening pattern in a yellow lithography process. The pattern is etched to remove the SiNx material from the area to the P-type metal contact electrode exposed for subsequent metal bump fabrication.

d. Define a pattern of metal bumps with photo-resist exposed areas of the exposed SiNx dielectric protection layer. It produces fine pitch indium bumps in thermal vapor deposition squares. Subsequently, the LED die was thermocompression bonded to the CMOS substrate with an FC-150 die bonder. Subsequent fabrications are filled under-fills to hold the microcrystal arrays. It completes all 192 × 64 LED microchip array active device processes.

e. It is to increase the difficulty of subsequent metal bump manufacturing process. It utilizes Dow Chemical's BCB-4026 material. The planarization

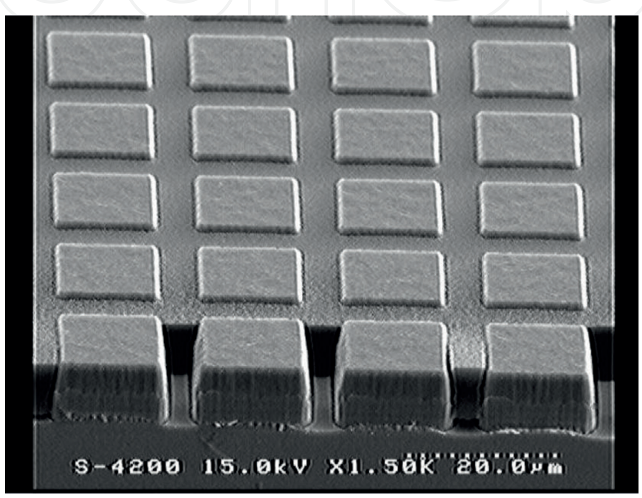


**Figure 3.**
*SEM observation of the flattened coating of the green microcrystalline LED array with BCB.*

coating is performed on the green light-emitting wafers that have been etched on the micro-chip LED array platform. It uses etching back to etch the BCB flat layer to the surface of the green light micro LED Mesa platform. It completes the planarization of the surface of the epitaxial wafer with the aforementioned insulating trenches, as shown in **Figure 3**.

## 4. Experiment and results

This is a micro-LED MEMS process combined with a CMOS substrate. The whole process requires the process of the clean room. Yellow light process developer causes a total N metal electrode surface damage. Therefore, when the common N metal electrode rewiring process is performed, the rewiring layer is stripped from the common N metal electrode. The ohmic metal contact electrode materials corresponding to the P-type and N-type semiconductor materials in the LED device manufacturing process are not the same. When the two metals are vapor-deposited, the heights of the bumps corresponding to the P-type and N-type regions are different when the indium bumps required for the subsequent fine-pitch bonding are produced due to different thicknesses of the metal plating films. This may affect the yield of LED die bonding with CMOS substrate metal. Therefore, the micro-chip LED array element prepared in this study extends the N-type ohmic contact electrode from the N-type semiconductor region to the LED platform in a metal rerouting (RDL) manner. This can improve the above problems. However, due to the different materials of P-type and N-type metals, the interface may be oxidized or etched and bombarded between two metal materials. As a result, the metal laminate is peeled off. Therefore, to improve this problem, the process steps are simplified in this process. The N-type metal extended LED platform is coated with a P-type ohmic contact electrode on the LED die array area. Afterwards, the N-type metal is directly self-interconnected. This avoids the problem of interface peeling between the two metal coatings.

The process result of the micro-chip LED array is shown in **Figure 4**. The difference between the blue and green light microchip LED array elements and the red light microchip LED array elements is only the depth of the platform etching and the BCB planarization coating process.

The I-V electrical test was performed on the blue and green microcrystalline LED arrays prepared as described above. The test results are as follows:

1. Blue-light micro-crystal LED array elements: VF ~ 2.9–3.1 V@20 mA/cm$^2$.

2. Green-light micro-crystal LED array element: VF ~ 3.1–3.4 V@20 mA/cm$^2$.

The Micro LED die is transferred to the circuit board in a large amount, and the brightness and contrast can be improved by integrating the micro lens array. An array of these display images, the Micro LED panel as shown in **Figure 5**, has scanning blood vessel positions and performs blood vessel product (PPG) detection.

At present, the reflective heart beat oxygen sensor can be divided into three types according to different light sources. The green LED mainly penetrates the skin to detect contraction and relaxation of the micro-vessels. It measures the heart rate through the vascular volume change calculation. The red and infrared LEDs are compared using different intensity of the two penetrating light sources. Because the absorption of light by oxygen and carbon dioxide in the blood is not the same, after optical signal processing, the value of hemorrhagic oxygen concentration can be converted as shown in **Figures 6** and 7. In addition, blood pressure and blood concentration can also be measured by measuring blood oxygen content or skin conductivity.

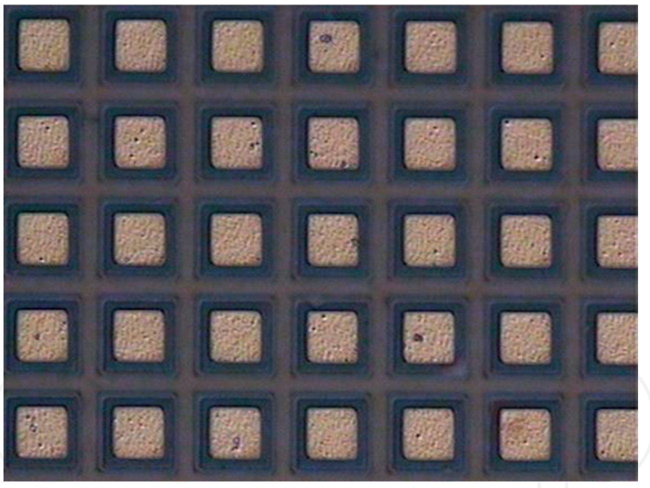

**Figure 4.**
*Blue and green light resolution 192 × 64, pixel cycle 19.2 μm linear arrangement of micro-crystal LED array elements OM observation photo.*

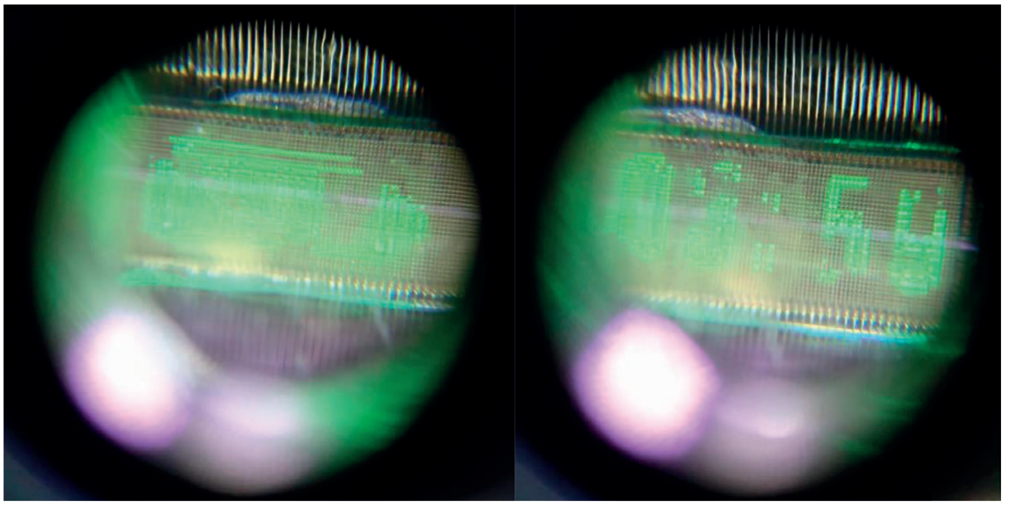

**Figure 5.**
*Micro LED panel image photo.*

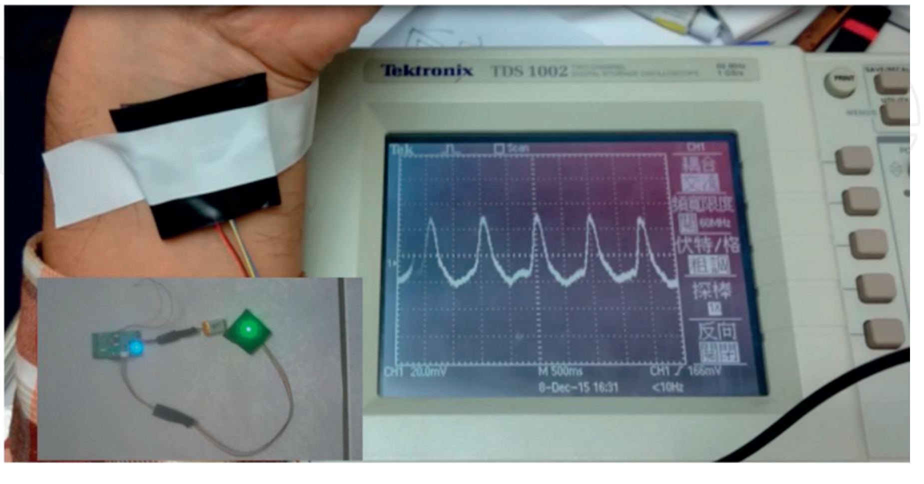


**Figure 6.**
*PPG signal acquisition medical system.*

On the other hand, it is used in remote/home care applications. The patient is equipped with an implantable BioMEMS sensor with wireless transmission capabilities, and the data is stored in the back-end medical care system through short-range wireless transmission. In addition to allowing patients and their families to manage

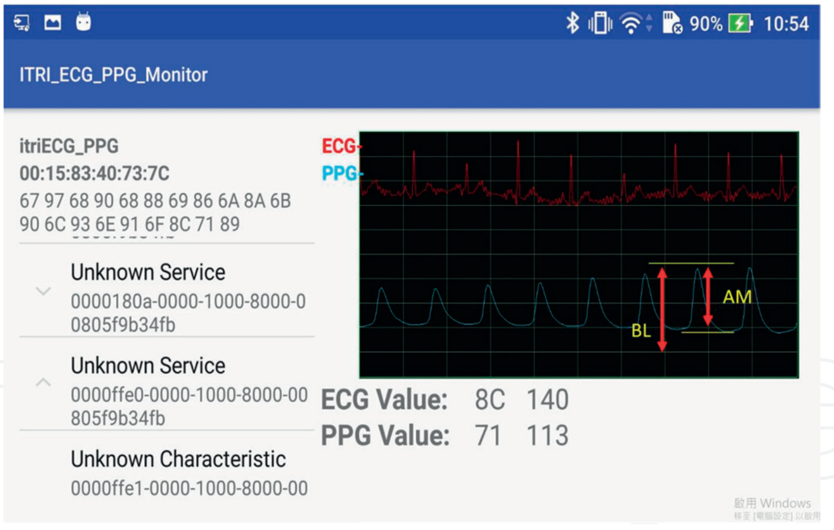


**Figure 7.**
*ECG & PPG signal.*

their own health, after a long time statistical analysis and analysis of their physiological testing data, the back-end medical system allows doctors to have more complete information for medical diagnosis. Some of the medical electronic components are planned to be integrated into personal terminal devices such as mobile phones, watches, clothing, and eyewear, to provide more complete and comprehensive care.

Aging society promotes medical electronics warming up, in the growing trend of social environmental development, such as population aging, cardiovascular disease and diabetes, self-monitoring and home care applications are gradually gaining popularity. Since the accuracy of the home-type biomedical detection instruments currently used in the market is not high, and it is inconvenient for patients to use and self-track management, the development of micro biomedical detection instruments using micro-electromechanical technology has become a goal of active development of relevant manufacturers.

The use of MEMS technology compatible with CMOS manufacturing to produce a new generation of BioMEMS biomedical sensors, in addition to being able to achieve miniaturization, due to the integration of related sensing elements, application of IC circuits, RF chips, etc. For technical and medical applications, improve its accuracy and the development of integrated applications. Looking ahead, the development of BioMEMS biomedical sensors not only facilitates the use of patients and healthcare personnel, but also integrates network transmission capabilities to further establish medical care networks and achieve the goal of remote/home care applications. Whether this goal can be achieved depends on whether the establishment of the industry's ecosystem and the evolution of technology are successful. ASIC-MEMS can be used by telemedicine providers in blood flow monitoring through Micro-LED arrays. Data can be uploaded to the cloud. Doctors in remote places can evaluate the data. The detection system provides feedback to local nurses and doctors. It is a way to increase the availability of the most advanced medical services in remote and rural areas using this technology. Detecting blood flow through ASIC-MEMS can reduce the cost of medicine. By doing so, it is possible to provide the world's most advanced medical services, including more developed countries and less developed countries.

## 5. Conclusions

In this article, we successfully designed and demonstrated an application specific integrated circuits (ASIC)-MEMS within the medical system. The Micro

LED die is transferred to the circuit board in a large amount, and the brightness and contrast can be improved by integrating the micro lens array. An array of these display images, the Micro LED panel, has scanning blood vessel positions and performs blood vessel product (PPG) detection. In low-power challenges remain, looking at the development of BioMEMS technology and applications, it can provide long-term monitoring applications that are more convenient and comfortable for patients with chronic diseases. However, there is still an important issue in the future development, is to achieve ultra-low power consumption. In order to reduce power consumption, relevant component manufacturers are actively developing low-power DSP and analog-digital converters (ADCs) dedicated to biomedical detection; and microsensor devices designed to automatically fine-tune the working cycle so that sensors can be used. ASIC-MEMS is best suited for use by telemedicine providers for blood flow monitoring through micro-LED arrays. This system is also the fastest to reach data can be uploaded to the cloud.

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## Author biography

**Dr. Jian-Chiun Liou** received a Ph.D. degree from the Institute of Nanoengineering and Microsystems, National Tsing Hua University, Hsinchu, Taiwan, in 2009. He joined the Printing Technology Development and Manufacturing Section of the Optoelectronics and Systems Laboratories at the Industrial Technology Research Institute (ITRI), Hsinchu, in 1999, where he focused on the ink-jet printing system. Since 2005, he has been a Project Leader working on a new MEMS architecture design and display application in the Electronics and Optoelectronics Research Laboratories, ITRI. In August 2014, he joined the faculty of the National Kaohsiung University of Applied Sciences (KUAS). In August 2017, he has joined the School of Biomedical Engineering, Taipei Medical University (TMU), Taipei 11031, Taiwan. Currently, he is a Professor of School of Biomedical Engineering at the TMU. His research interests are in the fields of Optoelectronics, ASIC design, bio-chip technology, optical MEMS technology, integration of ink-jet printhead processes, and display technology. He is a holder of 71 patents on ink-jet printheads, MOEMS, MEMS, and has written more than 28 SCI Journal papers and 38 conference technical papers on MEMS, optical-N/MEMS, and display-related and micro-/nanofluidics related fields. He has also co-chaired many conference technical sessions and has been an invited speaker in many related events. In addition, he has performed the following tasks: Advance project leader (ITRI), SCI Journal paper reviewer (PIER, JEMWA, MEE), and Research fellow (NTHU). To add, Dr. Liou was the recipient of the following honors: ITRI/OES Research Achievement Award (2004), ITRI Research Paper Publication Award (2004), ITRI/EOL Research Achievement Award (Individual person Award, 2005), ITRI/EOL Outstanding Advanced Research Silver Award (2005), ITRI/EOL Research Achievement Award (2006), ITRI/EOL Patents Reviewer (2007), Outstanding Research Award (2007), ITRI/EOL Patents Reviewer (2008), Outstanding Research Award (2010), ITRI/EOL Patents Reviewer (2009), ITRI/EOL Outstanding Research Award (2010), International R&D 100 Awards (2010), 1st International Contest of Applications in Nano-Micro Technology Award (2010)—OPTO- MEMS Device Application, ITRI Paper Awards (2012), ITRI/EOL

Outstanding Advanced Research Silver Award (2013), International Inventor Prize (2014), Nation Academic Award (2014). 2014 Invention Lifetime Achievement Award. 2015 "Design and fabrication of Monolithic CMOS / MEMS system with HV-ESD Clamp protected inkjet printhead." 2015 International Contest Application Contest in Nano-Micro Technology (Alaska, USA) "iCAN'15 7th Special Prize" 2015 International Contest of Application in Nano-Micro Technology (iCAN'15). Who's Who in the World® 2016 (33rd Edition). In 2016, "The 16th Wang Golden silicon semiconductor design and application contest winners": An ASIC designed to spray liquid medical wisdom DNA gene sequencing system. 2016 Third Prize Award and Best Supervisors: Jian-Chiun Liou, 2016 iCAN'16 France 2016 International Contest of Application in Nano-Micro Technology (iCAN'16 ESIEE Paris, July 7th, 2016): The Glove. 2017 "iCAN'17 Third Prize Award, and Education Star Award 2017 International Contest of Application in Nano-Micro Technology (iCAN'17 BEIJING): Cloud Health Care (CHC). 2017 Teaching Excellence Teacher Award. August 2017 Transferred to Taipei Medical University for medical electronics related fields in-depth study. He is a member of the IEEE and a reviewer for more than 20 international journals including the Applied Physics Letters, JMEMS, Microfluidics and nano-fluidics, and micro-devices. He has also been a consultant to three Taiwanese companies.

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