

## EDITORIAL BOARD

---

### ESTEEM ACADEMIC JOURNAL

VOLUME 9, NUMBER 1, JUNE 2013

Universiti Teknologi MARA (Pulau Pinang)

## ENGINEERING

### ADVISORS

Tan Sri Prof. Ir. Dr. Sahol Hamid Bin Abu Bakar, FASc  
Assoc. Prof. Mohd. Zaki Abdullah

### PANEL OF REVIEWERS

Prof. Ahmad Izani Md. Ismail (*Universiti Sains Malaysia*)  
Assoc. Prof. Dr. Farid Che Ghazali (*Universiti Sains Malaysia*)  
Assoc. Prof. Dr. Jaafar Jantan (*Universiti Teknologi MARA Shah Alam*)  
Dr. Ahmad Rafizan Mohamad Daud (*Universiti Teknologi MARA Shah Alam*)  
Dr. Bakhtiar Md. Shaari (*Politeknik Sultan Haji Ahmad Shah*)  
Dr. Cheng Lai Hoong (*Universiti Sains Malaysia*)  
Dr. Koay Mei Hyie (*Universiti Teknologi MARA Shah Alam*)  
Dr. Lau Tze Liang (*Universiti Sains Malaysia*)  
Dr. Mohamad Fahmi B. Hussin (*Universiti Teknologi MARA Shah Alam*)

### CHIEF EDITOR

Dr. Chang Siu Hua

### MANAGING EDITOR

Maryam Farooqi

### LANGUAGE EDITORS

Dr. Soo Kum Yoke  
Kamalanathan M. Ramakrishnan  
Zaira Mohd Nor

## FOREWORD

---










It is our great pleasure to present the ninth volume and first issue of the ESTEEM Academic Journal UiTM (Pulau Pinang): a peer-refereed academic journal devoted to all engineering disciplines. Since the beginning of the year, a number of articles have been sent to us, some of which are still under review in their first or second phase and the first five of them are being published now. Article submissions came from UiTM campuses across the country, with topics covering most, if not all, of the subfields of electrical, mechanical, civil and chemical engineering. We celebrate our good fortune in having a strong group of people who created the opportunity for this volume to be born and who made it happen.

First and foremost, we would like to extend our sincere appreciation and utmost gratitude to Associate Professor Mohd Zaki Abdullah, Rector of UiTM (Pulau Pinang), Associate Professor Ir. Bahardin Baharom, Deputy Rector of Academic Affairs and Dr. Mohd Subri Tahir, Deputy Rector of Research, Industry, Community & Alumni Network for their unstinting support towards the successful publication of this volume. Not to be forgotten also are the constructive and invaluable comments given by the eminent panels of external reviewers and language editors who have worked assiduously towards ensuring that all the articles published in this volume are of the highest quality. A special acknowledgement is dedicated to all committees, publication department, and many other relevant parties for making this volume a success. Their affective commitment and close cooperation have facilitated the realization of this volume. Last but not least, our greatest thanks go to all the authors for their interest in publishing their work with us. Their manuscripts are an expression of their commitment towards research and development which, in due course, would benefit the local, national and international communities. Hence, we would like to extend our warm invitation to all researchers who are actively involved in the field of engineering to publish their work with us.

Dr. Chang Siu Hua  
Chief Editor  
ESTEEM Academic Journal  
Vol. 9, No. 1 (2013)  
(Engineering)

## CONTENTS OF JOURNAL

---

1. Fabrication and Characterization of Flame Retardant 4 and Polydimethylsiloxane as Substrates for a Label-Free DNA Sensor 1  
Irni Hamiza Hamzah, Emilia Noorsal, Mohammad Nizam Ibrahim, Asrulnizam Abd Manaf and Othman Sidek  
 
2. Determination of the Young's Modulus of Miniaturized Cantilever by Measuring Micro-deflection Using the Phase-shift Shadow Moiré Method 12  
Lim Jiunn Hsuh, Mani Maran Ratnam, Ong Jiunn Chit and Chiang Ee Pin  
 
3. New and Old Buildings Microenvironment – An Indoor Air Quality Study 24  
Siti Fatimah Ghazali, Suhaily Amran, Lailatul Akmar Mat Nor, Siti Nazrina Camalxaman and Maimunah Mustakim  
 
4. Online OBE-CQI Tool for Engineering Programmes 37  
Mohaiyedin Idris, Mohd Affandi Shafie and Liaw Shun Chone  
 
5. Development of Fuel Additives to Enhance the Performances of Four-Cylinder Spark-Ignition Engine 48  
Mohd Khaizalfitri Mhd Yaakob, Mohd Azahar Mohd Ariff, Mahamad Hisyam Mahamad Basri, Sharzali Che Mat and Azmi Husin  
 

# FABRICATION AND CHARACTERIZATION OF FLAME RETARDANT 4 AND POLYDIMETHYLSILOXANE AS SUBSTRATES FOR A LABEL-FREE DNA SENSOR

Irni Hamiza Hamzah<sup>1</sup>, Emilia Noorsal<sup>2</sup>, Mohammad Nizam Ibrahim<sup>3</sup>, Asrulnizam Abd Manaf<sup>4</sup> and Othman Sidek<sup>5</sup>

<sup>1,2,3</sup>*Faculty of Electrical Engineering,  
Universiti Teknologi MARA (Pulau Pinang), Jalan Permatang Pauh, 13500 Permatang Pauh,  
Pulau Pinang, Malaysia.*

<sup>4</sup>*School of Electrical and Electronic Engineering, Universiti Sains Malaysia, Transkrian  
Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia.*

<sup>5</sup>*Collaborative microElectronic Design Excellence Centre (CEDEC), Universiti Sains  
Malaysia, Transkrian Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia.*

<sup>1</sup>*irnihami@ppinang.uitm.edu.my; <sup>2</sup>emilia.noorsal@ppinang.uitm.edu.my;*  
<sup>3</sup>*mnizam@ppinang.uitm.edu.my; <sup>4</sup>eeasrulnizam@eng.usm.my; <sup>5</sup>othman@cedec.usm.my*

## ABSTRACT

*Silicon, glass, and ceramic are commonly used base substrates for gold (Au) deposition on label-free DNA biosensors. This study aimed to investigate the suitability of applying flame retardant 4 (FR4) as a base substrate and polydimethylsiloxane (PDMS) as a coating substrate. A thermal evaporator was used to fabricate copper/nickel/Au metals and ensure even deposition of Au throughout FR4. UV exposure soft lithography and wet etching were applied to develop a three-electrode pattern on the metals fabricated on FR4. A simple and straightforward technique on PDMS–FR4 bonding was proved to work at the shear strength of 55 kPa. A cyclic voltammetry (CV) method was performed using the fabricated FR4 sensor to analyze bare Au, DNA immobilization and hybridization. The FR4-based Au fabricated with PDMS acted as a coating layer between terminals and sensing electrodes, and can thus be used as a label-free DNA sensor.*

**Keywords:** flame retardant 4; polydimethylsiloxane; cyclic voltammetry; immobilization; hybridization.

## 1. INTRODUCTION

Silicon, glass, and ceramic are commonly used as base substrates for gold (Au) fabrication by immobilizing them with the thiol group at the 5'-end of probe DNAs (Cho & Pak, 2002; Choi, Lee & Park, 2005, 2006; Choi, Kwon & Lee, 2006; Lee & Lee, 2004). These substrates are biocompatible but are not readily available in the market and; thus, they are expensive. Silicon and glass are hard and brittle, which make them difficult to drill and dice. Moreover,

these materials require expensive equipment such as a deep reactive ion etching (DRIE) instrument and a diamond-coated cutter for dicing.

The use of ceramic has been fully commercialized by DropSens® as seen in their model 220AT screen-printed electrode biosensor products. However, DropSens® uses the screen printing technique for Au fabrication. This technique is costly because it requires liquid Au and covers a very limited area for fabrication. Thus, many commercialized screen-printed electrodes utilize different types of metal for sensing and terminal electrodes, namely, silver at the exposed terminal layer and Au at the sensing electrodes. The Material International Anneal Copper Standard in Metal Statistics (American Metal Market Company, 1920) states that silver conductivity is 105 percent, whereas Au conductivity is 70 percent. The Chemical Rubber Company (CRC) Handbook (Lide, 2003) lists the electrical resistivity of silver and Au at 15.87 nΩ.m and 22.14 n Ω.m, respectively. These different conductivity and resistivity data prove that correlating current measurements using different metals fabricated on the same electrode from the sensing chamber to the terminal layer is possible. A uniform deposition of Au throughout the entire conducting tracks, that is, from the sensing to the terminal layer, is important to distinguish any metal correlation in the current measurement for cyclic voltammetry (CV) analysis during DNA detection.

Flame retardant 4 (FR4) is the most commonly used printed circuit board (PCB) material. FR4 is also used for harvesting electromagnetic energy in body-worn sensors (Hatipoglu & Urey, 2010) or body implantable devices (US Patent No. 6,591, 138) because of its low Young's modulus (15 GPa–20 GPa), which is 10 times lower than that of silicon (130 GPa–188 GPa) (Hopcroft, Nix, & Kenny, 2010).

Despite the progress in DNA label-free sensor fabrication, such as the development of microfluidic three-electrode cells (Chen, Lee & Chong, 2006; Oda, Sawada, Tsuchiya, Takao & Ishida, 2003; Triroj, Lapiere-Devlin, Kelley & Beresford, 2006); biosensor fabrication still relies on the use of silicon and glass as base substrates. Therefore, this work, was aimed to determine the suitability of non-biocompatible material, FR4, for Au deposition by using thermal evaporation and wet-etching. These methods are cost-effective and reliable for this purpose. Thermal evaporation is a common method used for metal deposition on silicon and glass. Wet etching is a reliable, simple, and cheap technique because it involves easily-available chemical solutions compared with the dry etching technique, which requires complicated and expensive materials such as DRIE chemicals and hazardous gases. The outcome of this work was a DNA label-free biosensor deposited by Au throughout the entire tracks with FR4 as the base substrate.

## 2. MATERIALS AND METHODS

Two types of metal were used as adhesion layers in this work, namely, titanium (Ti) and copper (Cu). The use of Ti or chromium (Cr) as an adhesion layer for Au fabrication on FR4 has been widely reported (Triroj et al., 2006; Choi et al., 2005, 2006; Cho & Pak, 2002). We also analyzed Cu to determine its suitability for Au fabrication. Cu is well known for its good adhesion with the FR4 substrate and has been widely used in the PCB industry. In all procedures, we used a 2 cm x 1.2 cm x 1.6 mm as the base material. All FR4 sheets were sequentially cleaned with acetone and isopropanol then dried with nitrogen gas.

## 2.1 Ti as an Adhesion Layer

Figure 1 shows a fabricated FR4-based substrate with the thickness of 30 nm Ti as an adhesion layer. It is achieved using direct current (DC) sputtering (Auto 500: BOC Edwards) of 100 percent Argon (Ar), a radio frequency (RF) power at 210 W, a vacuum pressure at  $5 \times 10^{-3}$  Torr for an exposure time of 2 min. Then, a thermal evaporator (Auto 306: Edwards UK) at  $6.0 \times 10^{-5}$  mbar and 68 A produced a 1  $\mu\text{m}$  Au electrode layer as shown in Figure 2. The electrode layer was spin-coated for 15 s with a positive photoresist (PR1-1000A: Futurrex Inc, USA). A positive mask (Hapmax (M) Sdn. Bhd., Penang, Malaysia) was applied on the coating before the electrode layer was UV-exposed (OAI 150 Exposure Timer: Teltec HK) for 45 s. The layer was then patterned by wet-etching of aqua regia, which is a mixture of nitric and hydrochloric acid in a volumetric ratio of 1:3. Similarly, the Ti layer was removed using a mixture of  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{O}_2$  and HF in a volumetric ratio of 20:1:1 and then dried in a nitrogen atmosphere.

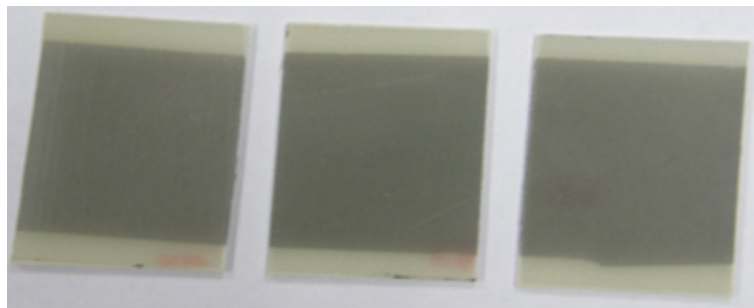


Figure 1: Ti that has been Sputtered on FR4-based Substrate.

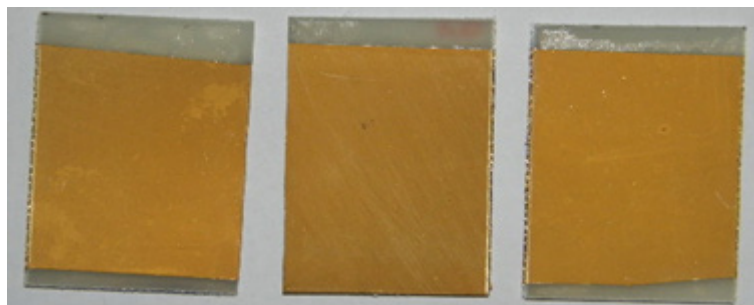


Figure 2: Au that has been Evaporated on Ti/FR4-based Substrate.

## 2.2 Cu as an Adhesion Layer

Cu is easily oxidized in an open-air environment. This behavior posed a big problem in the use of Cu as a base material. Therefore, acetic acid was used to eliminate the formation of an oxide layer before the fabrication of Au (Chavez & Hess, 2001).

A thermal evaporator (Auto 306: Edwards UK) at  $4.5 \times 10^{-5}$  mbar and 60 A produced a 10  $\mu\text{m}$  Cu layer. This layer was then immersed in acetic acid at 35 °C for 5 min–10 min until a shiny copper surface (no streaking or hazy residue) was observed. The samples were then dried with nitrogen.

A thermal evaporator (Auto 306: Edwards UK) at  $6.0 \times 10^{-5}$  mbar and 68 A produced 1  $\mu\text{m}$  Au electrode layer. This layer was then spin-coated for 15 s with a positive photoresist (PR1-1000A: Futurrex Inc, USA). A positive mask (Hapmax (M) Sdn. Bhd., Penang, Malaysia) was applied on the coating before the electrode layer was UV-exposed (OAI 150 Exposure Timer: Teltec HK) for 45 s. The layer was then patterned using wet-etching of aqua regia on a hot plate (35 °C), and was then dried in a nitrogen atmosphere.

### ***2.3 PDMS-FR4 Bonding Technique***

Four different design scales were produced on a positive mask by using AutoCAD 2002. These design scales had been patterned on the abovementioned Cu/Au layer fabricated on FR4. The areas of the designs were 0.26, 1.04, 4.16, and 6.50 mm<sup>2</sup>. PDMS (Dow Corning Sylgard 184) was mixed with a curing agent at a ratio of 10:1, and was then poured into a Petri dish containing a patterned square mold. PDMS was then placed in a vacuum box for 24 h before it was peeled off from the Petri dish (Abd Manaf, Nakamura, & Matsumoto, 2008). The PDMS relief was immersed in ethanol, sonicated for 5 min, and fully dried with nitrogen gas. A simple sealing process of PDMS as a coating layer onto the Au-fabricated glass sensor was described by Hamzah, Yu, Abd Manaf, Sidek and Chan (2010). A mixture of PDMS and curing agent with a ratio of 10:1 was spin-coated on an FR4 PCB and brought into contact with the prepared PDMS relief. The seal was then dried at room temperature (25 °C) for 6 h. Figure 3(a)–(c) demonstrate the detailed procedure.



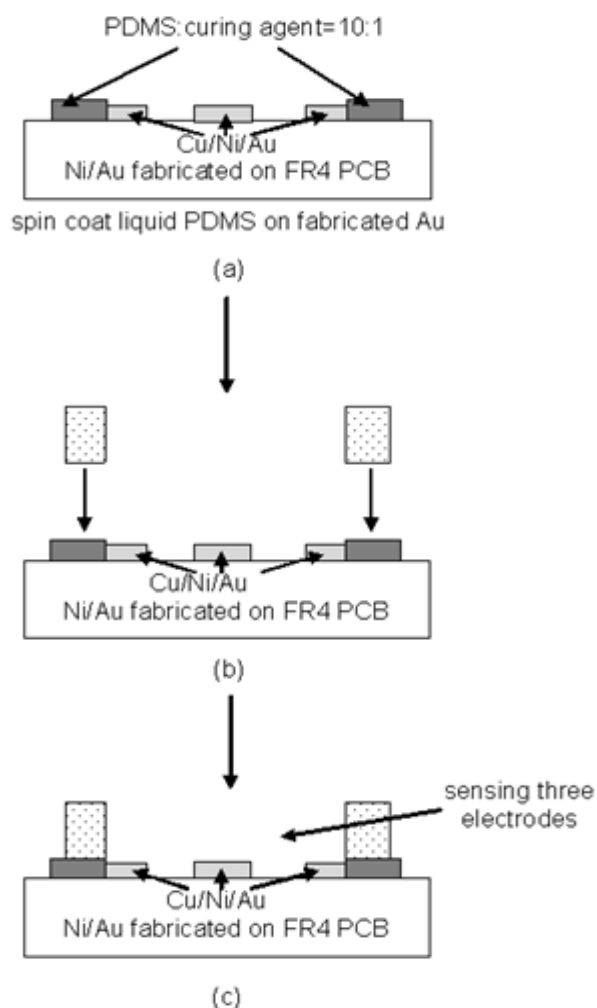


Figure 3: Fabrication Procedure for PDMS-FR4 Adhesive Bonding.

## 2.4 DNAs and Apparatuses

The DNA capture probe modified by the thiol group at the 3' end (5'-GGG GCA GAG CCT CAC AAC CT-(CH<sub>2</sub>)<sub>3</sub>-SH-3') and its complementary DNA target (5'-AGG TTG TGA GGC TCT GCC CC-3') were synthesized by Integrated DNA Technologies (Coralville, IA, USA). The thiol-modified DNA capture probe was treated with DTT and purified by elution through a NAP 10 column of Sephadex G-25 (Amersham Pharmacia Biotech, Uppsala, Sweden) before use.

Potassium ferricyanide (K<sub>3</sub>Fe(CN)<sub>6</sub>) and potassium chloride (KCl) were procured from Sigma-Aldrich Sdn Bhd (Malaysia). Deionized water was used throughout the study. CV measurements and data were compiled using  $\mu$ AutolabIII (Metrohm, KM Utrecht, The Netherlands) and analyzed using the software package NOVA 1.4. The immobilized DNA probe on the Au electrode was confirmed by CV by using 10 mM K<sub>3</sub>Fe(CN)<sub>6</sub> in 100 mM KCl solution. All CV experiments were performed at room temperature from -0.3 V to 0.3 V at 100 mV/s.



## 2.5 DNA Capture Probe Immobilization and Hybridization

The fabricated sensor was cleaned with deionized water and reversibly cycled in 0.05 M of sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) from 0.00 V to 1.25 V at a scan rate of 0.1 V/s. Probe immobilization was performed by placing 20 μL of a 1 μM DNA capture probe solution onto the Au electrodes for 1.5 h. Phosphate buffer (0.03 M K<sub>2</sub>HPO<sub>4</sub>, 0.02 M KH<sub>2</sub>PO<sub>4</sub> and 0.3 M KCl) was used to remove probes that were not absorbed. A CV measurement was used to confirm the immobilization step.

DNA hybridization was performed by the drop wise addition of 20 μL of a 4 μM DNA target solution onto the same Au electrodes (used for DNA probe immobilization) for 1 h. A CV measurement was also performed to detect the hybridized target after washing with phosphate buffer.

## 3. RESULTS AND DISCUSSION

### 3.1 Ti/Au Fabricated on FR4

We observed that Ti worked well on the FR4 surface. However, a major problem arose when we failed to remove the Ti/Au layer during the wet-etching process. Werbaneth, Lester and Pakulska (2007) also reported the unsuccessful removal of the Ti/Au seed layer by wet-etching on a silicon substrate. Some parts of Ti/Au layer were removed only after the photoresist removal process. The removal of the Ti layer by wet-etching took a long time, and the connection test by a digital multimeter showed no continuity throughout the layer.

### 3.2 Cu/Au Fabricated on FR4

Chavez and Hess (2001) reported a method of copper oxide removal using acetic acid and this method has been implemented in this work. Original native Cu on FR4 has been immersed in acetic acid at 35°C for 5 to 10 minutes until a shiny copper surface without streaking or hazy residue was observed. Upon removal, the samples were dried with nitrogen. DI water rinse is not required since nitrogen drying produces a streak-free and shiny surface (Chavez & Hess, 2001).

### 3.3 Selection of Sensor Area

The selection of the three-electrode fabricated sensor area was determined by the reversible redox-couple relationship described in Equation (1),

$$I_{pa} / I_{pc} = 1 \quad (1)$$

where  $I_{pa}$  is the anodic peak current and  $I_{pc}$  is the cathodic peak current. The peak current ratio can be used to examine if the system undergoes an adsorption effect (Triroj et al., 2006). CV analysis was performed using μAutolabIII (Metrohm, KM Utrecht, The Netherlands) equipped with the software package NOVA 1.4. Table 1 summarizes the results of  $I_{pa}$ ,  $I_{pc}$ , and the ratios of all these three-electrode areas.

Table 1: Peak Current Parameters for Fabricated Electrode.

Electrode area, A	$I_{pa}$ (uA)	$I_{pc}$ (uA)	Ratio of $I_{pa}/I_{pc}$
0.26 mm <sup>2</sup>	10.3	8.2	1.3
1.04 mm <sup>2</sup>	15.2	15.8	1.0
4.16 mm <sup>2</sup>	25.2	27.5	0.9
6.50 mm <sup>2</sup>	38.7	47.4	0.8

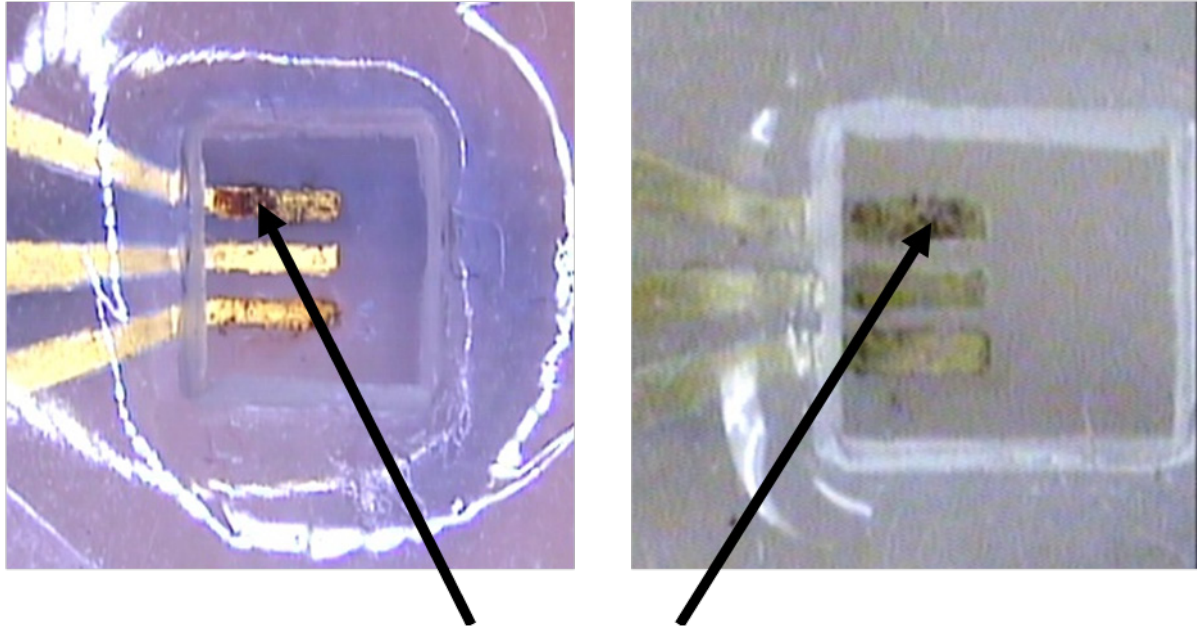
A peak current ratio less than unity indicates a weak adsorption of the reactant (ferricyanide) (Wopschall & Shain, 1967) because of the decrease in electrode surface area. The weak adsorption of the reactant generally led to an enhanced cathodic peak current, whereas on the reverse scan, the weak adsorption led to a smaller increase in the anodic peak current. The reactant was difficult to reduce because of its significantly weak adsorption. The reduction occurred at a higher cathodic potential. Consequently, the cathodic peak increased.

Peak current ratios became greater than unity when the anodic peak current was dramatically enhanced and when the cathodic peak current was slightly increased. Thus, the product (ferrocyanide) was weakly adsorbed onto the electrode (Wopschall & Shain, 1967).

Table 1 shows that an area of 1.04 mm<sup>2</sup> has a reversible redox-couple relationship ratio near unity. Hence, an area of 1.04 mm<sup>2</sup> was used throughout our research as shown in Figure 4. However, the erosion produced at the counter electrode (CE) after it was used for a few minutes with the electrolyte affected the reliability of the sensor, as revealed in Figure 5. To overcome this problem, Brett and Brett (1993) stated that the surface area ratio of the CE to the working electrode (WE) should be larger than 10 to support sufficiently the current generated at the WE. Therefore, another sensor whose areas of the CE, WE, and the reference electrode were 6.25 mm<sup>2</sup>, 0.581 mm<sup>2</sup>, and 1.04 mm<sup>2</sup>, respectively, was designed as in Figure 6. The ratio of the area of CE to WE was 10.8. The CV analysis of this sensor produced the following values: 5.76  $\mu$ A ( $I_{pa}$ ), 5.26  $\mu$ A ( $I_{pc}$ ), and 1.1 (ratio).



Figure 4: A Complete Fabricated Sensor for the Area Size of 1.04 mm<sup>2</sup>.



Erosion produced at CE for  $1.04 \text{ mm}^2$

Figure 5: Erosion Produced at CE Electrode for  $1.04 \text{ mm}^2$  Electrode Area Size for  $2 \text{ mM K}_3\text{Fe}(\text{CN})_6$  Solution and  $10 \text{ mM K}_3\text{Fe}(\text{CN})_6$  Solution in  $0.1 \text{ M KCl}$ .

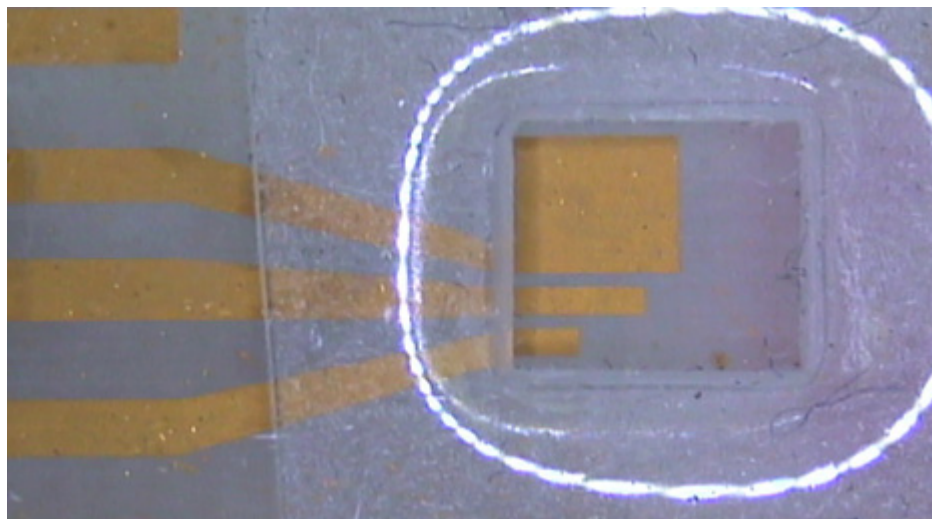


Figure 6: A Close-up Photo on the Final Structure of PDMS-FR4 Adhesive Bonding.

### **3.4 CV Analysis of Bare Au, DNA Immobilization, and Hybridization**

Figure 7 shows the CV data and measurement results of bare Au electrodes, DNA probe immobilization, and DNA hybridization for the sensor. The anodic peak current of the immobilized DNA (red curve) was less than that of bare Au (blue curve). The formation of a barrier via the Au-thiol bond that inhibited electron transfer (Steel, Levicky, Herne, & Tarlov, 2000) resulted in a lower peak current. The anodic peak current of the hybridized DNA (green curve) was lower than that of the immobilized DNA because at this stage, double-stranded DNAs (dsDNA) were formed. The dsDNA was larger and formed a barrier to inhibit electron

transfer. As a result, dsDNA prevented the redox response of the bulk solution (potassium ferricyanide ions) after the immobilization or hybridization of DNA on the Au electrode surface (Choi et al., 2005).

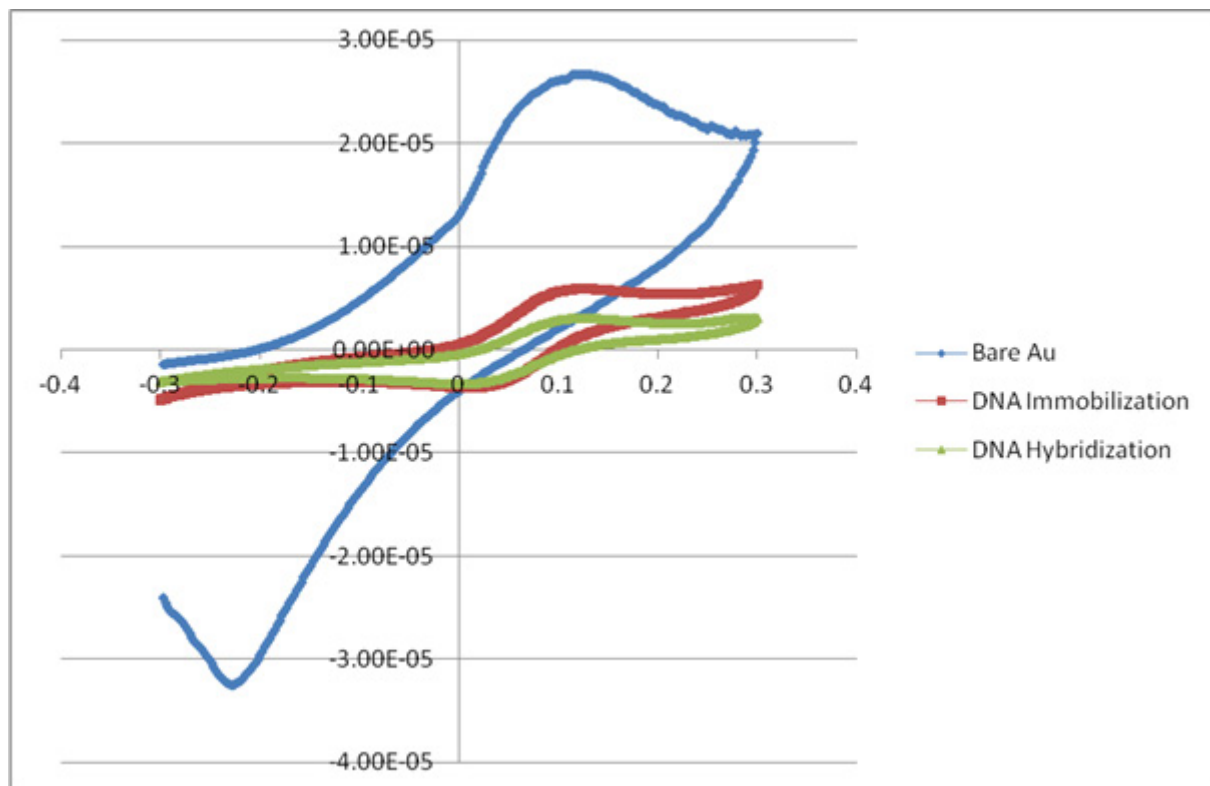


Figure 7: CV Measurement for Bare Gold, DNA Immobilization and DNA Hybridization for Fabricated PDMS-FR4 Insulated Free Electrodes Sensor.

#### 4. CONCLUSION

An adhesion layer of Cu, which was free from oxide formation, was compatible for adhesion with an FR4 surface and an Au layer through thermal evaporation, UV exposure soft lithography, and wet-etching techniques. Liquid PDMS with a pre-polymer-curing agent ratio of 10:1, which was dried at room temperature (25 °C) for 6 h, adhered well on the FR4 surface. CV analysis performed on the fabricated FR4-based sensor revealed that an area of 1.04 mm<sup>2</sup> for all three electrodes produced a reversible redox-couple relationship ratio near unity. The area ratio of CE to WE was modified to obtain a reliable Au surface to be used with the ferricyanide redox reaction. A final FR4-based (evaporated with Cu/Au) sensor with CE, WE, and RE areas of 6.25, 0.581, and 1.04 mm<sup>2</sup>, respectively, was reliable for redox reaction, DNA immobilization, and DNA hybridization. Thus, an FR4-based substrate with a uniformly deposited Au layer was successfully fabricated using thermal evaporation, UV exposure soft lithography, and wet etching. This sensor can be used as a DNA label-free biosensor.



## REFERENCES

- Abd Manaf, A., Nakamura, K., & Matsumoto, Y. (2008). Characterization of miniaturized one-side-electrode-type fluid-based inclinometer. *Sensors and Actuators A*, *144*, 74-82. doi:10.1016/j.sna.2008.01.003
- American Metal Market Company. (1920). *Metal statistics*. New York, US: Author.
- Brett, C. M. A., & Brett, A. M. O. (1993). *Electrochemistry—principles, methods, and applications*. London, UK: Oxford Univ. Press.
- Chavez, K. L., & Hess, D.W. (2001). A novel method of etching copper oxide using acetic acid. *Journal of The Electrochemical Society*, *148*(11), 640-643. doi: 10.1149/1.1409400
- Chen, Y., Lee, E. Y., & Chong, S. (2006). A fast, sensitive and label free electrochemical DNA sensor. *Journal of Physics: Conference Series*, *34*, 204-209. doi:10.1088/1742-6596/34/1/034
- Cho, S., & Pak, J. J. (2002). Fabrication of a multi-electrode array DNA sensor for electrochemical genotyping. *Journal of the Korean Physical Society*, *41*(6), 1054-1057. doi: 10.3938/jkps.41.1054
- Choi, Y. S., Lee, K. S., & Park, D. H. (2005). Hybridization by an electrical force and electrochemical genome detection using an indicator-free DNA on a microelectrode-array DNA chip. *Bulletin of the Korean Chemical Society*, *26*(3), 379-383. doi:10.5012/bkcs.2005.26.3.379
- Choi, Y. S., Lee, K. S., & Park, D. H. (2006). Genomic detection using an indicator-free DNA on a DNA chip microarray. *Current Applied Physics*, *6*(4), 772-776. doi:10.1016/j.cap.2005.04.037
- Choi, Y. S., Kwon, Y. S., & Lee, K. S. (2006). Electrochemical DNA detection using indicator-free target DNA on a DNA chip. *Proceedings of Nanotechnology Materials and Devices Conference* (pp. 342-343). Gyeongju, South Korea. doi:10.1109/nmdc.2006.4388758
- Fischell, D. R., & Upton, A. R. M. *Low frequency neurostimulator for the treatment of neurological disorders*. US Patent No. 6,591, 138.8 July 2003.
- Hamzah, I. H., Yu, C. Y., Asrulnizam Abd Manaf, Sidek, O., & Chan, Y. Y. (2010). The effect of photoresist thin film on cyclic voltammetry measurement for DNA immobilization and hybridization of indicator-free DNA sensor. *Optoelectronics and Advanced Materials-Rapid Communications*, *4*(12), 2103-2107. <http://oamr.inoe.ro/download.php?idu=1409>
- Hatipoglu, G., & Urey, H. (2010). FR4-based electromagnetic energy harvester for wireless sensor nodes. *Smart Material Structure*, *19*(1), 1-11. doi:10.1088/0964-1726/19/1/015022

- Hopcroft, M. A., Nix, W. D., & Kenny, T. W. (2010). What is the young's modulus of silicon?. *Journal of Microelectromechanical Systems*, 19(2), 229-238. doi:10.1109/jmems.2009.2039697
- Lee, B. S., & Lee, S. (2004). Synthesis of thiol-functionalized ionic liquids and formation of self-assembled monolayer on gold surfaces: effects of alkyl group and anion on the surface wettability. *Bulletin of the Korean Chemical Society*, 25, 1531-1537. doi:10.5012/bkcs.2004.25.10.1531
- Lide, D. R. (2003). *Properties of Solids; Electrical Resistivity of Pure Metals*. Boca Raton, Florida: CRC Press.
- Oda, C., Sawada, K., Tsuchiya, T., Takao, H., & Ishida, M. (2003). Integrated electrochemical DNA sensors with microfluidic channel reactor. *7<sup>th</sup> International Conference on Miniaturized Chemical and Biochemical Analysis Systems* (pp. 371-374). Squaw Valley, California USA.
- Steel, A. B., Levicky, R. L., Herne, T. M., & Tarlov, M. J. (2000). Immobilization of nucleic acids at solid surfaces: Effect of oligonucleotide length on layer assembly. *Biophysical Journal*, 79, 975-981. [http://dx.doi.org/10.1016/S0006-3495\(00\)76351-X](http://dx.doi.org/10.1016/S0006-3495(00)76351-X)
- Tiroj, N., Lapierre-Devlin, M. A., Kelley, S. O., & Beresford, R. (2006). Microfluidic three electrode cell array for low-current electrochemical detection. *IEEE Sensors Journal*, 6(6), 1395-1402. doi:10.1109/jsen.2006.884444
- Werbaneth, P., Lester, T., & Pakulska, J. (2007). Removing gold seed-layer materials using reactive ion etch. *MICRO magazine.com*. Retrieved from <http://micromagazine.fabtech.org/archive/03/07/werbaneth.html>
- Wopschall, R. H., & Shain, I. (1966). Effects of adsorption of electroactive species in stationary electrode polarography. *Analytical Chemistry*, 39(13), 1514-1527. doi:10.1021/ac50156a018