

## Fabrication of Amorphous Silicon Microgap Structure for Energy Saving Devices (Fabrikasi Struktur Mikrogap Silikon Amorfus untuk Peranti Jimat Tenaga)

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### ABSTRACT

*We report here the fabrication of microgaps electrodes on amorphous silicon using low cost techniques such as vacuum deposition and conventional lithography. Amorphous silicon is a low cost material and has desirable properties for semiconductor applications. Microgap electrodes have important applications in power saving devices, electrochemical sensors and dielectric detections of biomolecules. Physical characterization by scanning electron microscopy (SEM) demonstrated such microgap electrodes could be produced with high reproducibility and precision. Preliminary electrical characterizations showed such structures are able to maintain a good capacitance parameters and constant current supply over a wide ranging differences in voltages. They have also good efficiency of power consumption with high insulation properties.*

*Keywords: Dielectric detection of biomolecule; microgap electrodes; power saving devices*

### ABSTRAK

*Kami laporkan fabrikasi elektrod mikrogap silikon amorfus menggunakan teknik kos rendah seperti pemendapan vakum dan litografi konvensional. Silikon amorfus adalah bahan kos rendah dan mempunyai sifat yang berguna dalam aplikasi semikonduktor. Elektrod mikroluag mempunyai aplikasi penting dalam peranti jimat kuasa, sensor elektrokimia dan pengesanan dielektrik biomolekul. Ciri-ciri fizikal menggunakan mikroskop electron imbasan (SEM) menunjukkan elektrod mikroluag boleh dihasilkan dengan kebolehlungan yang tinggi dan persis. Pencirian elektrik awal menunjukkan struktur seperti ini boleh menghasilkan parameter kapasitor yang baik dan pembekal arus malar untuk julat voltan yang lebar. Ia juga mempunyai kecekapan penggunaan kuasa dengan sifat penebat yang tinggi.*

*Kata kunci: Elektrod mikrogap; pengesanan biomolekul dielektrik; peranti jimat kuasa*

### INTRODUCTION

Amorphous silicon (a-Si) has been a subject of extensive academic research for many years (Jing et al. 1996). As the number of its possible applications increases, detailed studies of its properties in specialized applications become increasingly important. A-Si has been used in products, such as solar cells (Schropp & Zeman 1998), thin film transistor, liquid crystal displays, and diodes (Street 2000). A-Si photodiodes have also been used for imaging devices, such as linear image sensors for facsimile and scanners (Kakinuma et al. 1990; Tan & Castner 1981), two-dimensional arrays for medical imaging and high-energy particles and X- and  $\gamma$ -ray detectors (Powell et al. 1998; Westfield 1999). Unlike crystalline Si whose absorption maximum is in the infrared part of the spectrum, a-Si with materials such as hydrogen show the highest photoconductivity in the visible (VIS) red region, which makes it an ideal material for many photoelectrical applications using the visible light source (Ristova et al. 2003).

Recently microgaps and nanogaps electrodes received enormous research attentions because of their potential applications in power saving devices (Dhahi et al. 2011a), electrochemical sensors (Xing et al. 2010) and biomolecule

detection with low-level of power supply (Dhahi et al. 2011b). Microgaps structures are also increasingly being used in advanced integrated circuits that are typically composed of multiple conductive layers and multiple insulating layers in a plurality of active semiconductor substrate regions (Dhahi et al. 2010; Dhahi et al. 2011c).

Present methods in producing the sensor electrodes are made of a catalytic layer on top of a porous membrane that include electrodeposition (Ishiji et al. 2004), pasting (Brain 2002), or screen-printing (Hart et al. 2004) technologies. A wide application of electrochemical sensors is limited by fabrication technologies that are not suitable for mass production due to high costs of the catalytic agent. Thin film vacuum deposition is a suitable technology to overcome these limitations (Dhahi et al. 2011d).

In the present paper, we have used low cost techniques such as vacuum deposition and conventional lithography (Dhahi et al. 2011e) to fabricate microgaps on low cost substrate such as amorphous silicon (Dhahi et al. 2011f; Dhahi et al. 2011g). Homogeneous microgaps with Al-electrodes were obtained. Preliminary studies demonstrated that such microgaps structure have a high capacitance and can be operated over wide ranging voltage differences with a strong-level of insulation.

MATERIALS AND METHODS

A 100 m n-type silicon wafer was used as a substrate to fabricate the microgap structure. Two masks, one for the amorphous (a) silicon microgap and other for the aluminium (Al) electrode were designed by AutoCAD software. The designed masks were printed onto chrome glass surfaces and purchased from a commercial company (Photonic Pte. Limited, Singapore). The first mask is shown in Figure 1 and the corresponding chrome mask is demonstrated in Figure 2. The specification of the first mask is represented in Table 1. Please note, when  $S_d$  is large, the micro-gap figure becomes sharper, and vice versa. Figure 3 and 4 show the design of the Al-electrode masks.

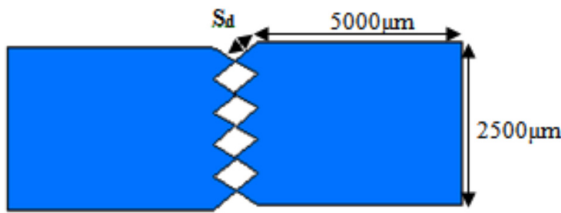


FIGURE 1. Design specification of the first mask (5000 μm × 2500 μm)

TABLE 1. Dimension specification of the side angel ( $S_d$ )

$S_d$	μm
1	1,100
2	1,000
3	900
4	800
5	700
6	600

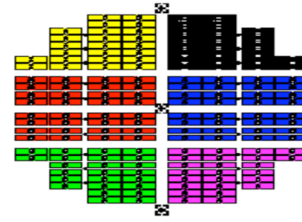


FIGURE 2. The actual first mask on chrome glass surface. It consist of 160 dies with 6 different designs represented in different colors

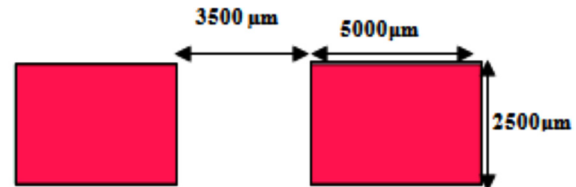


FIGURE 3. Design specification of the Al-electrodes mask (5000 μm × 2500 μm) separated from each other by 3500 μm

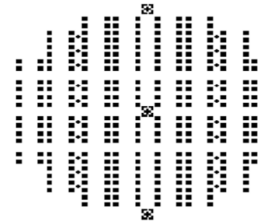


FIGURE 4. The actual second mask (Al-electrode) on chrome glass surface. It consists of 160 dies with identical designs

MICROGAP FABRICATION

The fabrication process flow is shown in Figure 5. It started with cleaning of an n-type Si-wafer followed by deposition of a 150 nm thick SiO<sub>2</sub> layer on it (a) using a plasma-enhanced chemical vapor deposition equipment

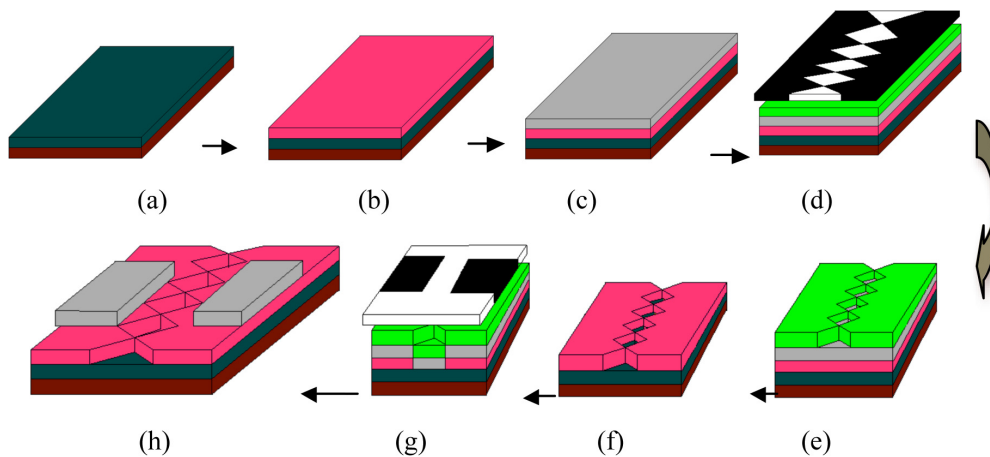


FIGURE 5: The process flow for microgap fabrication. (a) SiO<sub>2</sub> layer on silicon wafer; (b) amorphous silicon on SiO<sub>2</sub> layer; (c) protective Al-layer on amorphous silicon; (d) photoresist coating sandwiched between first mask and Al-layer; (e) developed resist after photolithography; (f) fabricated microgaps on amorphous silicon after wet and dry etching; (g) lithography process for the Al-electrode, and (h) final microgap structure with Al-electrode

(PECVD). The same equipment was applied to deposit a 100 nm a-Si layer (b). In the next step, a 105 nm thick Al layer was deposited onto the a-Si layer (c) by physical vapor deposition (PVD) as a hard mask to avoid any damages of the a-Si layer during the etching/RIE process. In the photolithography process (d), a layer of positive photoresist was applied onto the Al surface prior to the exposure to ultraviolet (UV) light through mask 1. After development, only the unexposed resist is existed (e). The Al-layer was wet-etched and the resist was removed. Subsequently, a-Si-layer was dry etched using reactive ion etching (RIE) to realize patterned microgap structures on a-Si layer (f). A layer of 105-nm Al substrate was deposited on the patterned a-Si microgap structure, the resist was coated and was exposed to UV-light through mask 2 (g). The wet etching process for the Al substrate was performed before removing the resist. Finally, a structure of the Al-electrode with a-Si micro-gaps was obtained (h).

#### STRUCTURE CHARACTERIZATION

The final device with microgap structure was physically characterized using a scanning electron microscope (SEM) (JOEL). Electrical characterization was performed using a dielectric analyzer (DA) (Novocontrol Technologies, Hudsangen, Germany) and semiconductor parameter analyzer (SPA) (Agilent 4156C). Capacitance and current-voltage were measured with air in the microgap spaces.

#### RESULTS AND DISCUSSION

Figure 6 shows the SEM images of the microgaps fabricated on amorphous-Si material. The original mask was designed

to obtain five microgap structures as shown in Figure 1. It was confirmed from the SEM images (Figure 6) that two gaps were of 7.3  $\mu\text{m}$ , one was of 7.6  $\mu\text{m}$ , and another two were of 7.9  $\mu\text{m}$  in dimensions. Thus the mean size of the microgaps was  $7.6 \pm 0.26 \mu\text{m}$ .

The capacitance- frequency (C-F) profile of the fabricated microgap electrodes obtained from DA is shown in Figure 7. The C-F characterization demonstrated that at the extreme frequencies (too low or too high), capacitance significantly falls down and  $\text{Tan}\delta$  dramatically increases.  $\text{Tan}\delta$  is a ratio of useless current to the useful current in electrical system (Dhahi et al. 2011h). It indicates the insulation status of an electrical device.  $\text{Tan}\delta < 1$  indicates the device utilizes electrical power with a good efficiency. C-F profile of fabricated microgap structures reveals a constant capacitance and stable  $\text{Tan}\delta$  over a wide ranging frequencies ( $10^{2.5}$  to  $10^6 \text{ Hz}$ ) (Figure 7), suggesting the structures can be used in highly stable electrical appliances as they can withstand a long range frequencies. Over these frequency ranges ( $10^{2.5}$  to  $10^6 \text{ Hz}$ ), a stable and low  $\text{Tan}\delta (< 1)$ , indicates such devices can be operated with a low-level of current supply as they efficiently utilizes electrical energy with minimum wastages.

The CV curve of the fabricated microgap structures on n-type Si substrate with air in the gap spaces obtained from SPA is shown in Figure 8. It demonstrates that at high voltages ( $\pm V$ ) capacitance decreased significantly (Dhahi et al. 2011h). However, capacitance is very high and robust over the range of -0.5 to 1.5 V, supporting the conclusion drawn from the C-F curve (Figure 7) that the fabricated microgap structures have potential applications in power saving devices over a fairly wide voltage differences.

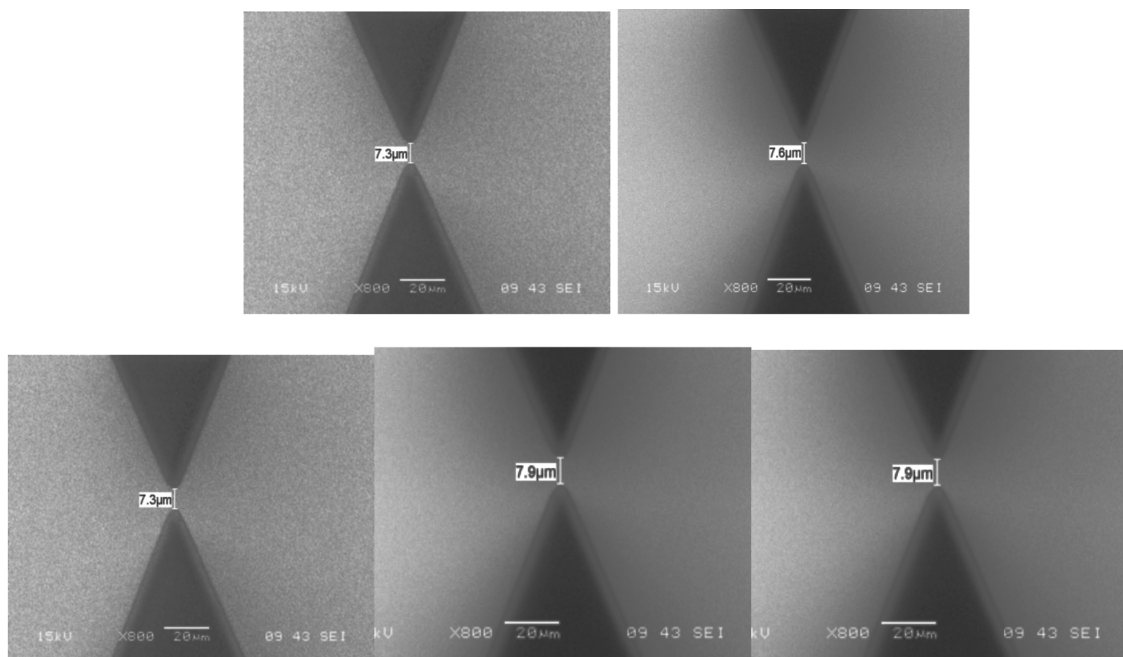


FIGURE 6. SEM images of the fabricated micro-gaps structure

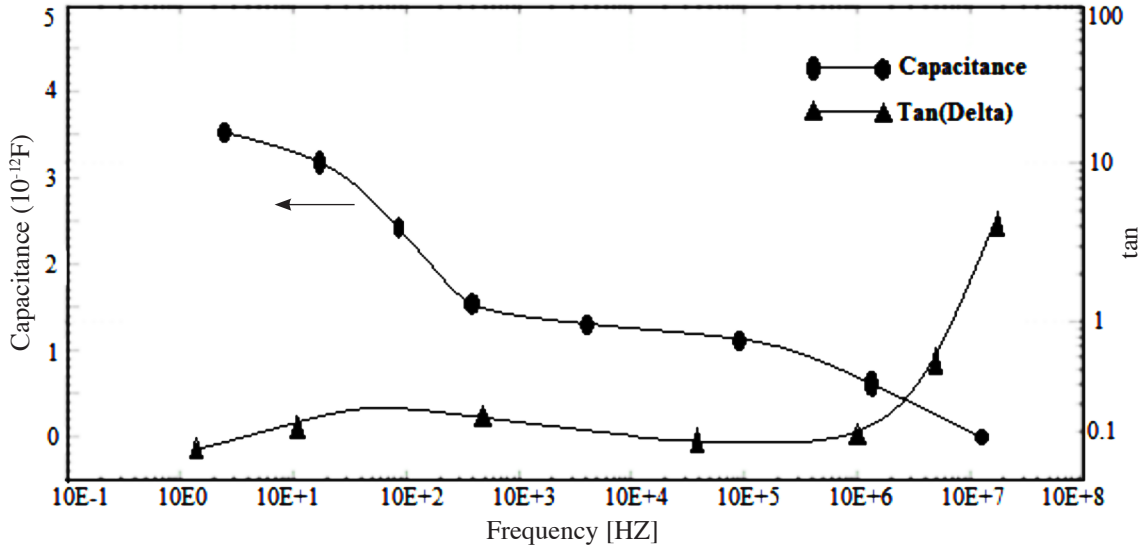


FIGURE 7. C-F characterization curve of a-Si micro-gap structure

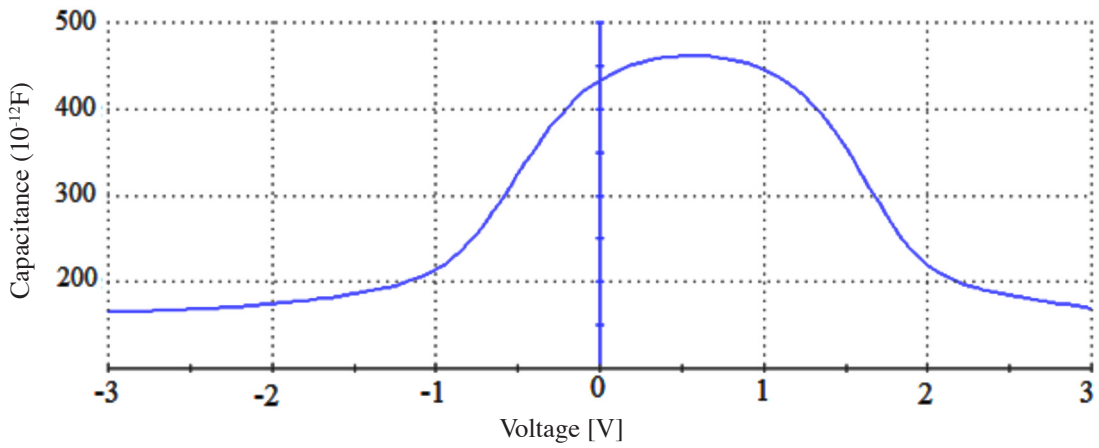


FIGURE 8. The CV curve of micro-gap structures

The IV curve of the microgap electrodes is shown in figure 9. It demonstrate the electrode allows a minimum level of electricity to pass through the gap over a wide ranging

voltage of  $\pm 4$  V. This reflects the fabricated structure can be used in devices that can tolerate a wide fluctuation of power supply.

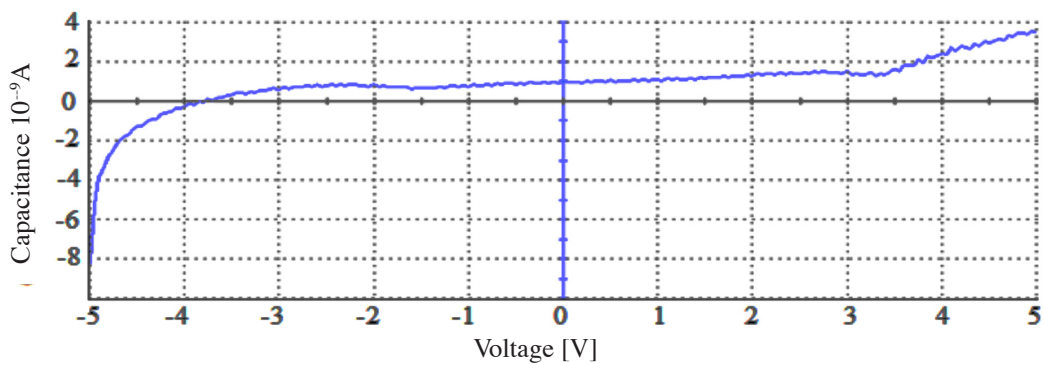


FIGURE 9. IV capacitor curve of the microgap structure

## CONCLUSION

A convenient method to fabricate micro-gap electrodes of desired dimension on amorphous silicon substrate was developed. The homogeneity of the gaps was confirmed from SEM studies. Electrical characterizations (C-F, CV and IV profiles) demonstrated the structures are able to maintain a good capacitance profile over wide ranging frequencies and voltages differences, suggesting its potential application in energy saving devices and long lasting capacitors.

## ACKNOWLEDGMENTS

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