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Improving the rectifying properties of metal/semiconductor junction using novel material: Zam-zam

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ABSTRACT

In this work, a 1.42 μm thin layer using zam-zam water has been formed as a thin interlayer to modify the Schottky barrier height (SBH) between Au contacts and Si substrates. Better rectifying ratio (2.14×10^5 at ± 1 V bias) has been obtained according to Au/p-Si Schottky diode. The variations in the electrical characteristics of Au/zam-zam (ZZ) layer/p-Si Schottky diode have been investigated as a function of temperature, x-ray irradiation and illumination by using current–voltage (*I–V*) measurements. It has been found that the *I–V* characteristics of the Au/ZZ layer/p-Si Schottky diode strongly depend on temperature, x-ray irradiation and illumination. The temperature dependent of the junction parameters such as ideality factor and the barrier height has been explained by barrier inhomogeneities by assuming a Gaussian distribution of barrier heights at the interface of the junction materials. Furthermore, the *I–V* characteristic of the Au/ZZ layer/p-Si Schottky diode has showed a good illumination response like a solar cell.

1. Introduction

Metal-semiconductor rectifying contacts have wide applications for their low turn-on voltage, fast recover time, low junction capacitance and high frequency compatibilities. Although Schottky devices based on Si have been used in most of these applications, the leakage current is high in Si and Schottky barrier height is not adjustable. In theory, Schottky barrier height depends on the metal work function but in practice, it may be independent on the metal work function due to the fact that Fermi level at the interface may be pinned relative to the valance band by the density of the dangling bonds. Sometimes the pinning of Fermi level may be important in metal-semiconductor devices due to the high density of surface states (about10^{15}–10^{16}/eV cm^2). In a bulk metal–semiconductor contact, metal-induced gap states (MIGS) may lead to Fermi level pinning, and to the modification of the Schottky barrier height [1–3].

MIGS is based on the penetration of metal wave functions into the semiconductor and this causes the formation of energy states in the semiconductor bandgap. Furthermore, the surface states because of bond polarization at the interface may cause Fermi level pinning. In this situation, Fermi level can be pinned at the charge neutrality level. According to both reasons of Fermi level pinning, we can conclude that this pinning depends strongly on the type of surface, cleaning conditions of the bulk semiconductor wafer, quality of cleave and surface contamination. A thin insulator or low conductive interface layer between the metal and the semiconductor can be a possible solution to de-pin the Fermi-level or modulate the Schottky barrier height (SBH). It is desired that these surface states should be low for adjusting the barrier height and to obtain unpinned Fermi level. Furthermore, in the practical applications of the Schottky diodes, the barrier height is very sensitive to the cleaning process and ambient conditions. Namely, in metal-semiconductor device, Schottky barrier height might be affected from the preparation conditions. For example, in Si, a native oxide layer may occur on the surface of the Si as a SiO_2 layer, which is a perfect insulator and has about 9.5 eV band gap. Forming a thin layer on the semiconductor or passivating the surface of the semiconductor can modify the nature of the rectifying device. Furthermore, the growth of an interlayer on an inorganic semiconductor can modify the nature of the metal/semiconductor MS contacts due to the dipole layer between the interlayer and semiconductor.

Zam-zam (ZZ) water is accepted as holy by Muslims and many Muslims believe that the source of zam-zam water is divinely

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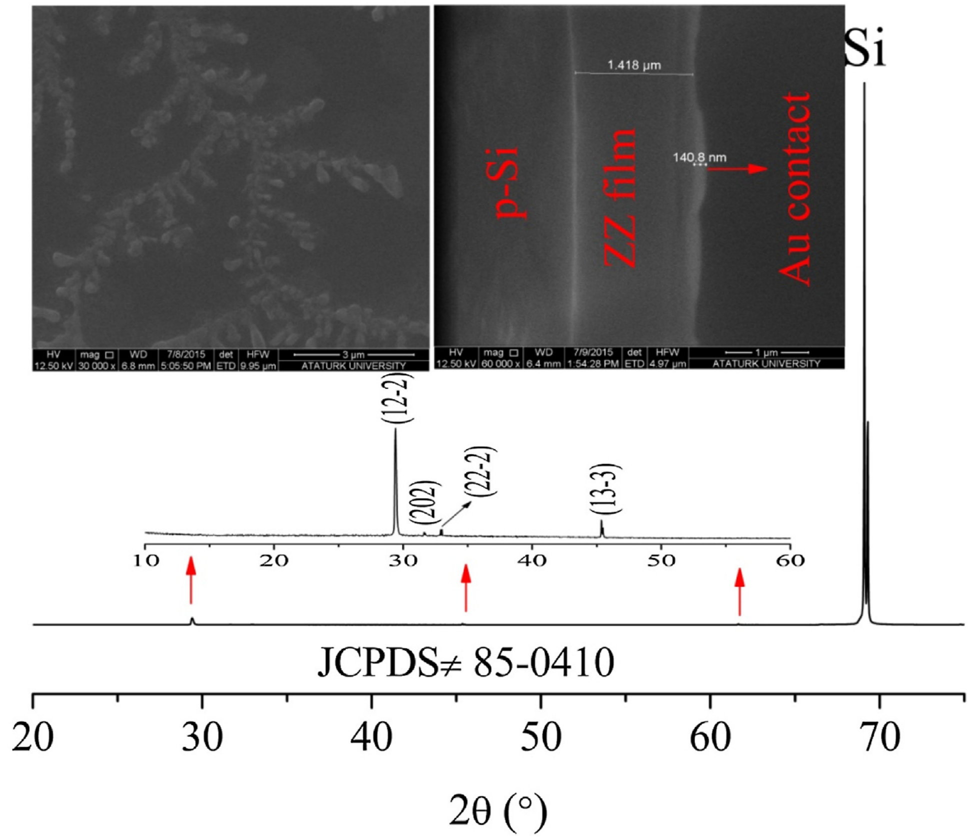

Fig. 1. Typical XRD patterns and inset figure shows the top view and cross sectional SEM image of the zam-zam film.

Table 1
Concentrations of various elements determined in zam-zam.

Element	Conc. (µg/L)	Element	Conc. (µg/L)
Li	2.95	K	7524.32
B	234.1	Ca	10,255.41
Na	4710.6	Ti	0.05
Mg	10,451.22	V	25.23
P	3.62	Cr	0.49
Fe	<0.05	Se	3.48
Co	0.05	Sr	521.45
Ni	0.05	Mo	49.62
Cu	0.19	Rh	3728.34
As	6.74	Ba	40.81

blessed, able to satisfy both hunger and thirst and it cures many illnesses. It is colourless, odourless, its pH ranges from 7.9 to 8.0 and it is similar to seawater. However, seawater is very condenser and the density of it ranges from about 1020–1029 kg/m^3, depending on the salinity and temperature. For example, its density is 1.0 kg/l, at 4 °C. Furthermore, many impurities in distilled water are removed through distillation. For this purpose, the water is distilled and it is condensed. In addition, zam zam will has a higher density than distilled water and this higher density of zam zam with respect to distilled water is due to heavy metals in zam zam. However, it has a distinct taste and the nature of the water is still unclear. Although there is limited studies to analyse zam-zam water, it is known that it involves many elements such as Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr, and Zn [4]. Namely, in general, zam-zam water includes two main ions as positive and negative such that it contains high levels of some minerals: calcium, magnesium and fluoride. Zam zam has a higher electrical conductivity than potable water since it contains many ions or minerals given in Table 1. Some research reported that the conductivity of zam zam is about 1390 µS/cm [5,6]. Since each element plays major role in the vital function of the cells of human body, it has been investigated for many areas. However, according to our current knowledge, we can say that there is no research on the electronic device applications of zam-zam water. Thus, we think that the results given in the present study have a directive feature for the future studies and will provide an important contribution to the literature. The purpose of this study is to use zam-zam water on silicon for metal/interlayer (zam-zam)/semiconductor device and to analyse the response of the current-voltage characteristics of Au/ZZ layer/p-Si rectifying device.

2. Experimental procedure

The analyses of zam-zam has been carried out by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at East Anatolian High Technology Research Center (DAYTAM) of Ataturk University and the results of analyses is given in Table 1. According to our analyses, 20 elements have been determined in zam-zam.

p-Si wafer with (100) orientation, 400 µm thickness and 1–10 Ω-cm resistivity was used for the fabrication of the devices. At 10^{-5} Torr pressure, Al was evaporated onto silicon for ohmic contact by DC magnetron sputtering. Then, we have deposited zam-zam water to form a film onto the surface of Si. ZZ water has been provided from Saudi Arabia and dropped on p-Si wafer directly and then it has been dried in a highly pure (1000 class) glove box for 24 h. Top view and cross sectional SEM images of the ZZ film formed on p-Si are given in Fig. 1. According to the SEM images, ZZ crystals have unique connections like nano brunch. Besides, the cross sectional SEM image supports our idea that ZZ use as the interlayer material and the film thickness is determined as about 1.42 µm. Next, 10 circle Au dots with 7.85×10^{-3} cm^2 area