

## Shallow junction determination and boron profiling using electrochemical capacitance-voltage (ECV)

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(Received 26 February 2009)

A method for determining the carrier concentration profile and the depth of  $p$ - $n$  junction boron diffusion in silicon using electrochemical capacitance-voltage (ECV) technique is studied. Boron profiles obtained show to be agreed with theoretical profiles and junction depths shows no significant differences compared to theoretical calculation. Therefore the ECV technique is found to be suitable for profiling the diffusion process and to determine the electrical junction depth.

### I. INTRODUCTION

The design and characterization of semiconductor devices relies on reliable determination of the active carrier concentration profiles in the structures. Different techniques have been applied. The most common are conventional capacitance-voltage (CV) and spreading resistance (SR) profiling [1-4]. In the conventional CV technique, a metal Schottky contact is formed on the surface and a stepped reverse bias is applied to incrementally deplete thin regions of the semiconductor [1,5]. From the differential capacitance the carrier profile can be deduced. Though experimentally simple, and capable of good resolution and accuracy, CV profiling has a limited profiling capability due to breakdown at high reverse bias and due to the insufficient field screening when applying a high field to low-doped regions [1,5]. Although SR does not suffer from such a depth limitation and is capable of profiling through junctions, the technique requires elaborate sample preparation, probe conditioning and calibration procedures [2,3,6]. Furthermore the profile depends on the choice of the correction factor algorithm and assumes bulk mobilities are preserved [6].

However, the electrochemical capacitance-voltage (ECV) technique overcomes these limitations. The metal used in conventional CV technique is replaced by an electrolyte that is capable of performing a Schottky contact in reverse bias and etching material in forward bias. By alternating CV measurement with etching, a doping level profile can be obtained to any arbitrary depth. The ECV technique is well established for III-IV materials now has been demonstrated for profiling of both  $n$ - and  $p$ -type silicon at moderate doping levels [1,7-9].

The ECV technique depends on the fact that the width of a reverse-biased depletion region of a semiconductor junction device depends on the doping concentration. The ECV profiling method has been used with Schottky diodes using metal electrodes or liquid electrolyte.

When a dc bias voltage is applied to the electrolyte, the Schottky diode is formed and the reverse bias produces a depletion region of width  $W_d$ . The capacitance is defined by [10]

$$C = -\frac{dQ}{dV} \quad (1)$$

where  $Q$  is the charge in semiconductor. The negative sign shows the negative charge in the semiconductor in depletion region. The space-charge increment  $dQ$  is given by [10]

$$dQ = qAN_A(W_d)dW_d \quad (2)$$

and the bias is increased by [10]

$$dV = \frac{qW_dN_A(x_d)dW_d}{\epsilon\epsilon_0} \quad (3)$$

where  $W_d$  is a width of the depletion region.  $N_A$  is doping concentration in the semiconductor material,  $\epsilon_0$  and  $\epsilon$  are the permittivity of vacuum and the relative permittivity of the semiconductor material, respectively.  $A$  is the measurement area. The capacitance of reverse-biased junction is expressed as [11]

$$C = \frac{\epsilon\epsilon_0A}{W_d} \quad (4)$$

From differentiating Eq. (4) with respect to the voltage, the doping concentration  $N_A$  can be obtained as [11]

$$N_A(W_d) = \frac{C^3}{q\epsilon_0\epsilon_rA^2(dC/dV)} = \frac{2}{q\epsilon_0\epsilon_rA^2[d(1/C^2)/dV]} \quad (5)$$

A depth profile can be obtained by dissolving the semiconductor electrolytically. Dissolution of the semiconductor relies on the presence of holes. The etched depth,  $W_r$ , is can be expressed by the total charge transferred by integration the dissolution current,  $I$ , [9]

$$W_r = \frac{M}{ZF\rho A} \int_0^t I dt \quad (6)$$

where  $M$  and  $\rho$  are the molecular weight and the density of the semiconductor, respectively.  $F$  is the Faraday constant ( $9.64 \times 10^4$  C) and  $z$  is the charge transferred per molecule dissolved. For silicon  $z = 3.8$  and GaAs  $z = 6$ . Therefore, the total measurement depth of the carrier concentration is given by [9]

$$x = W_d + W_r. \quad (7)$$

**II. MATERIALS AND METHODS**

This process involved the uses of *N*-Type boron doped silicon wafers of <100> in orientation. The wafers resistivities are ranging from 0.05 to 1.0  $\Omega$ -cm. Prior to processing, the samples were cleaned using the RCA cleaning procedure. In this experiment, Spin-On Dopant (SOD) technique has been used. SOD is a primarily spin on glasses that have the dopant atoms incorporated in a chemical form [12,13]. They are applied directly onto the silicon substrate by spinning and they act as an infinite or finite source of dopant atoms during the thermal diffusion [12,13].

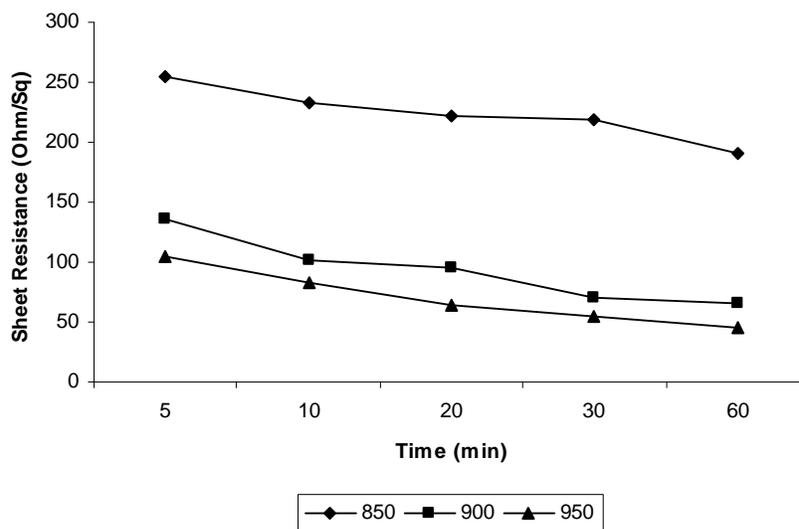
BDC1-2000 supplied by Futurrex Incorporation is a boron-containing spin-on dopant that used as diffusion

source in this experiment [14]. The diffusion process started with spinning process, which is done at 4000 rpm for 45 sec using photoresist spinner. These coated samples were cured at 200°C for 10 minutes on hot plate prior to diffusion. Drive-in diffusion was then carried out in High-Temperature Modu-Lab Horizontal Diffusion Furnace at 900°C with five different diffusion times; 5, 10, 20, 30 and 60 minutes. Subsequently, the diffused samples were deglazed in 10% HF solution and were rinsed in deionized (DI) water. Then these samples were dried in  $N_2$  gas at room temperature.

The measurements and calculations were carried out on the ECV equipment model PN4300PC. The electrolyte used in this work is of 0.1 M  $NH_4F.HF$  (Ammonium Biflouride). Before mounting the ring in the electrochemical cell, the samples were shortly dipped in 10% HF to remove oxide layer, then rinsed several times in DI water and  $N_2$ . To profile the *p-n* junctions, the front and back contacts were used.

**III. RESULTS AND DISCUSSION**

Fig. 1 shows the dependence of the boron sheet resistance on diffusion time and temperatures. The temperature was varied between 850°C and 950°C and the diffusion time was chosen between 5-60 minutes. The sheet resistance show a similar trend which is the sheet resistivity decreased with an increase of the diffusion time and temperature. The sheet resistance ranged from 255 to 44  $\Omega/cm^2$  is successfully achieved using thermal diffusion and SOD technique. This value is suited with sheet resistance needed for doping CMOS transistor [15]. However for ECV profiling, the samples diffused at 900°C are only characterized.



**FIG. 1.** Dependence of boron sheet resistance on diffusion time and diffusion temperature.

Fig. 2 shows boron profiles obtained from ECV measurement. The ECV profile measurement indicates the electrical active atoms were used to measure the boron concentration profile. Since the experimental procedure is considered as constant source diffusion, the results showed are a complementary error function (erfc) distribution. The surface concentration results in  $2-3 \times 10^{19} \text{ cm}^{-3}$ . All profiles near the peak region are

nearly flat ( $> 10^{19} \text{ cm}^{-3}$ ) and this is due to a higher diffusion coefficient at higher concentration [15]. It is noted that the differences in the background concentration of the doping profiles is due to side wall effects in the ECV measurement [16] or to slight differences in the base doping concentrations of the wafer [10].

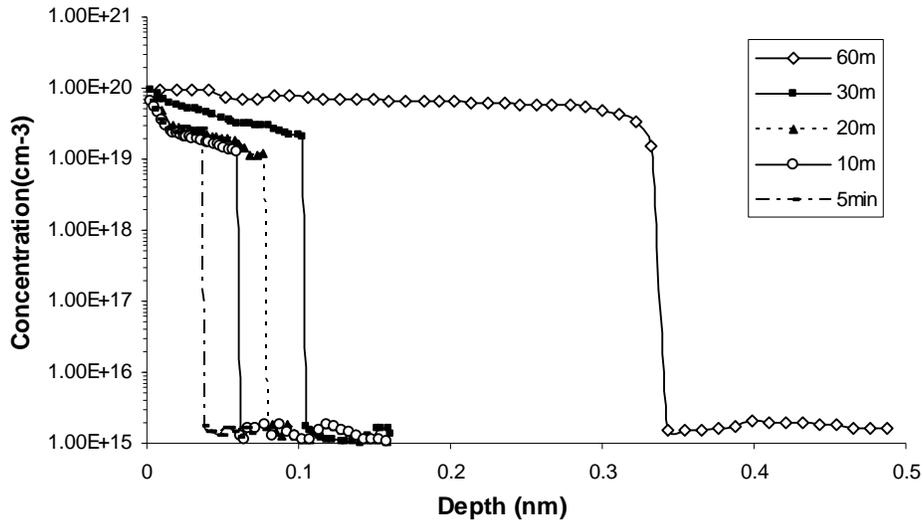


FIG. 2. Boron concentration profiles by ECV technique.

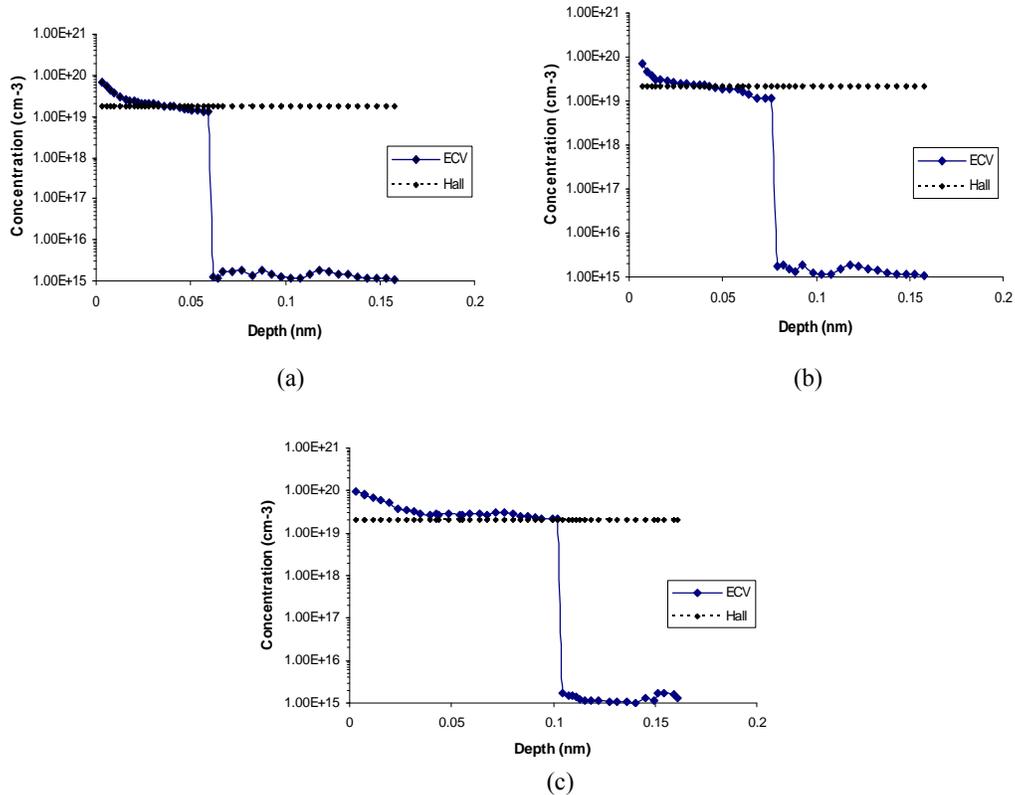


FIG. 3. ECV profiles and Hall results of boron diffusion. (a) 900°C, 10 min (b) 900°C, 20 min and (c) 900°C, 30 min.

**TABLE I.** Comparison between junction depths obtained using ECV technique and theoretical calculation.

Samples	Time (min)	Theoretical Depth (nm)	Experimental depth (nm)
BA	5	36	32
BB	10	50	59
BC	20	71	76
BD	30	87	102
BE	60	123	332

Samples were also profiled and characterized by Hall Effect technique. Three samples were chosen to be characterized using Hall measurement and the results are indicated in Fig. 3 above. It is shown that, the active boron concentration profiled using Hall technique is in the range of  $1.76 - 2.17 \times 10^{19} \text{ cm}^{-3}$ . These values seem to be fitted well with ECV results.

Junction depth is defined as the point where the diffused dopant concentration equals to the substrate dopant concentration [17]. In this work, the junction depths is given by

$$x_j = 2\sqrt{D_T} \operatorname{erfc}^{-1}\left(\frac{N_o}{N_B}\right) \quad (8)$$

where  $D_T$  is the diffusion coefficient at the diffusion temperature,  $T$ ,  $t$  is the diffusion time,  $N_o$  is the initial boron surface concentration and  $N_B$  is the background concentration. The experimental junction depth and calculated junction depths are depicted in Table I above. From the Fig. 1, we observed that the junction depth increased with the diffusion time. The junction depth obtained from ECV technique is in the range of 35-334 nm. This result is then compared to theoretical calculation. There are no significant differences between the measurements except for 60 minutes diffusion with the result from experiment is just about 37% deeper than theoretical calculation.

#### IV. CONCLUSIONS

It is known that junction formation is also dependent with diffusion temperature and diffusion time. The higher the temperature and the longer the time, the deeper the junction will be obtained. High temperature is required to activate the dopant to diffuse in silicon. This work has proved that at  $900^\circ\text{C}$ , boron is electrically active to diffuse in the silicon. However, the junction measured using ECV profiler is deeper than junction depth obtained from theoretical calculation. In conclusion, the effectiveness of the ECV technique for profiling boron diffusion in Silicon has been demonstrated. This technique is easily capable of

accessing carrier concentration in silicon at levels of at least up to  $3 \times 10^{19} \text{ cm}^{-3}$ .

#### ACKNOWLEDGEMENT

The authors would like to thank all the staff members of School of Microelectronic Engineering, Northern Malaysia College University of Engineering, Prof. Dr. Burhanuddin Yeop Majlis, En. Nurul Afzan Omar and all staff members Institute of Microelectronic and Nanotechnology (IMEN), UKM for their technical advice and contributions either directly or indirectly, and also to Government of Malaysia for granted this project through Intensification of Research in Priority Areas (IRPA) 09-02-15-0215-SR0013/06-06.

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