Sheet Resistance of Cobalt/Silicon Ohmic Contacts Fabricated by Laser-Induced Diffusion

Maha M. Ahmed, Ragheed S. behnam

Department of Physics, College of Science, University of Ajman, Ajman, United Arab Emirates

Abstract
In this work, the electrical characteristics of the ohmic contacts fabricated by laser-induced diffusion of cobalt dopants in silicon substrates were studied. The main parameters affecting these characteristics are the laser fluence and number of laser pulses used for irradiation. An Nd:YAG laser operating in Q-switching mode and wavelength of 1064nm was used to irradiate the contact region of cobalt on silicon substrate to induce the diffusion of cobalt dopants into the structure of the silicon. The electrical measurements showed a reasonable modification as the ochmic contact resistance decreased with increasing laser fluence as a result of the enhanced diffusion of metallic dopants into the semiconductor substrate.

Keywords: Laser-induced diffusion; Cobalt dopants; Silicon devices; Ohmic contact
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1. Introduction

Ohmic contacts are main parts in all microelectronics and nanoelectronics based on the interfaces between semiconductors and metals [1,2]. These contacts provide the regions required to provide or extract the electrical current and potentials to the functional structures existing between such contacts within the circuit [3,4]. These contacts necessarily should show as low as possible electrical resistance against the current passing through them towards other parts in the circuit architecture [5,6]. Therefore, the reduction of electrical resistance of ohmic contacts may determine the quality of operation of such circuits and hence the whole system based on such circuits [7,8]. One of the most common method to decrease the electrical resistance of ohmic contact is the enhanced diffusion of conductive dopants in the semiconducting substrates those form the fundamental elements of the microelectronics and nanoelectronics [9,10]. Precise diffusion can be achieved by using a precise energetic tool to provide sufficient energy to induce the metallic dopant to penetrate deeper inside the surface layers of the semiconducting substrate [6]. Such precise tool is a powerful laser beam focused on the contact region [11,12]. Figure (1) shows the principle of laser-induced diffusion of metallic dopant into a semiconducting substrate [13].

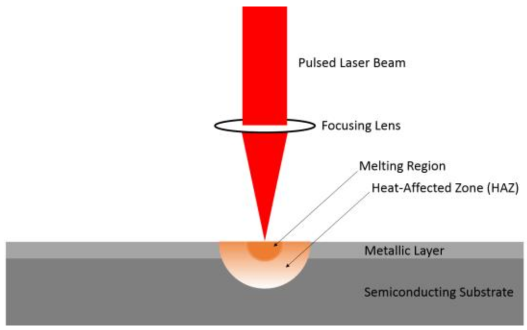

Fig. (1) The principle of plasma-induced bonding technique

In this work, a Q-switched Nd:YAG laser was used to enhance the electrical characteristics of ohmic contacts fabricated by laser-induced diffusion of cobalt dopants into silicon substrates.

2. Experimental Part

A (100)-oriented p-type silicon wafers of 500µm thickness and 3 Ω.cm resistivity were used in this work. Also, a 50µm thick layer of high purity (99.99) cobalt (Co) was deposited on the silicon substrate by thermal evaporation technique.

Both samples, Si and Co, were washed with distilled water then rinsed in ethanol and subjected to ultrasonic waves for 10 minutes, then dried by hot air. The silicon samples were then cleaned with HF for 5 minutes to remove any residual oxides which have existed on their surfaces. Both samples were softly grinded and polished to obtain flat surfaces. Then, these samples were rinsed in ethanol to remove acids then dried to be ready for processing.

The sample was mounted inside an evacuated chamber under vacuum of 10^{-6} mbar at room temperature. The Q-switched Nd:YAG laser used in this work was operating with 1064nm wavelength, 0.18-0.36 J pulse energy, 300 µs pulse duration, TEM_{00} operating mode, and 10 Hz repetition rate. The laser beam was focused on the sample surface using a 5cm focal lens to increase the laser intensity.

The electrical measurements were carried out using a Farnell dc power supply (0-30V) and KEITHLEY 616 digital electrometer (current range of 10^{-1}-10^{-7} A with accuracy of ±0.5%). All measurements were performed at room temperature.

3. Results and Discussion

Figure (2) shows the variation of sheet resistance of the ohmic contact irradiated with 2.29×10^{7} J/cm^2 laser fluence with the number of laser pulses incident on the ohmic contact region. It is clear that the sheet resistance has decreased to 5% of its initial value (from 4000 to 200 Ω/sq) as the number of laser pulses irradiating the contact region was increased from 5 to 100. This increase in the number of laser pulses has resulted in accumulation of laser energy on the contact region and hence induce much more Co dopants to penetrate into the Si substrate and hence increase the conductivity, i.e., decrease the electrical resistance, of the formed structure.

It is also observed that the further increase in the number of laser pulses more than 100 may not cause reasonable decrease in the sheet resistance because the accumulation of laser energy on the irradiated region may form a new phase of the Co-Si that exhibits metallic characteristics much more than ohmic ones [14].

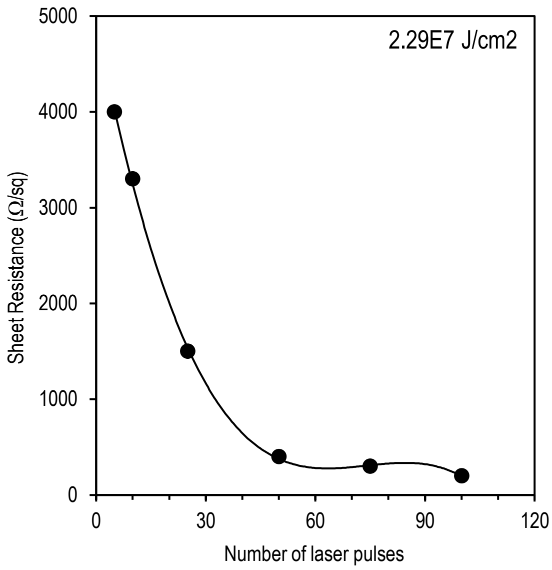

Fig. (2) Variation of sheet resistance of ohmic contact with the number of laser pulses

Figure (3) shows the effect of increasing laser fluence on the sheet resistance of the sample. The linear reduction in the sheet resistance may inform about the continuous decrease with increasing laser fluence until the Co-Si system begins to exhibit metallic characteristics rather than ohmic ones. However, further increase in laser fluence may result in irreversible deformation in the sample if the damage threshold is exceeded as a consequence of the cumulated thermal energy on the irradiation region [15,16].

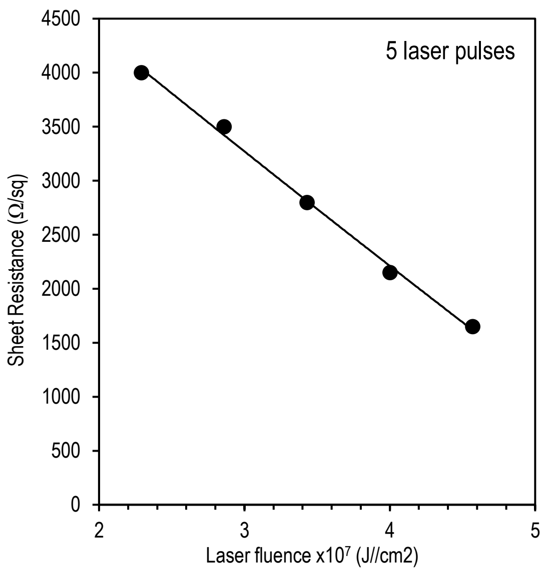

Fig. (3) Variation of sheet resistance of ohmic contact with the laser fluence

Further measurements are essentially required to introduce the behavior of electrical resistance within the heat-affected zone (HAZ) that receives lower laser fluence than the irradiation region, as shown in Fig. (1). This may require much more sophisticated experimental setup, which can be the subject of a future work.

4. Conclusions

A Co_3O_4-Si heterojunction was produced by plasma-induced bonding techniques. The structural characteristics explained the good bonding interface between the Co_3O_4 and Si samples. Electrical measurements showed reasonable enhancement in the heterojunction characteristics compared to that produced by another techniques. Despite the complexity imposed by the plasma processing system, production of heterojunctions with such enhanced characteristics has advantages of low cost and large size devices.

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