

# Low resistance nonalloyed In ohmic contacts to n-Si irradiated by Nd: YAG laser pulses

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In the present work, the feasibility of formation near-ideal ohmic contact of In/n-Si by 300  $\mu$ s duration Nd:YAG pulsed laser processing has been demonstrated. Several laser pulses energy densities have been used. Topography of the irradiated region with different conditions was extensively discussed to support other measurements to evaluate the ohmic contact quality. I-V characteristics in the forward and reverse bias and barrier height measurements have been studied for different irradiated samples to determine the laser energy density that gives best ohmic behavior. Comparing the current results with published results, it is found that these results are competitive and meet the standards of good ohmic contact, specific contact resistance of  $1.9 \times 10^{-4} \Omega \cdot \text{cm}^2$  has been obtained at  $21.1 \text{ J} \cdot \text{cm}^{-2}$  laser energy density, which is the lowest value ever reported for In/n-Si.

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## 1. Introduction

Ohmic contact with low specific resistance is a major standing problem that should be taken in consideration in the design and fabrication of electronic devices, such as bipolar transistors, light emitted diodes, solar cells [1-4] etc.

Interface states between metal and semiconductor arise from dangling bonds at the interface. When a metal is deposited on semiconductor, interface states pin the interface Fermi level, making the Schottky barrier height independent of the metal work function. Ohmic contacts have been conventionally prepared by decreasing the width of the Schottky barrier so that, electrons can tunnel through it. Many approaches have been reported to obtaining good ohmic contact such as: (1) high-electron concentration under the ohmic contact that can be achieved by conventional doping techniques (diffusion or ion implantation) [5], (2) employing multilayer metallization in which one of the metals deposited is an acceptor impurity and the other metals are donors [6], (3) electrolytical metal tracer technique (known as ELYMAT) [7], and (4) passivation of semiconductor surface to obtain interface states that have a negative Schottky barrier [8].

Laser has been used widely in making ohmic contacts onto semiconducting materials especially Si (n, p). In this study, ohmic contacts by long pulse Nd:YAG laser was produced on Si without using dopant diffusion. Characteristics of ohmic contacts were characterized.

## 2. Experimental details

n-type monocrystalline Si wafer of (111) orientation and 3-5  $\Omega \cdot \text{cm}$  resistivity was irradiated by Nd:YAG laser

pulse (1.064  $\mu$ m wavelength and 300  $\mu$ s duration) after degreasing and oxide removing of the treated region using HF acid. The irradiation was achieved under different laser energy densities (see Table 1).

*Table 1. Irradiation parameters.*

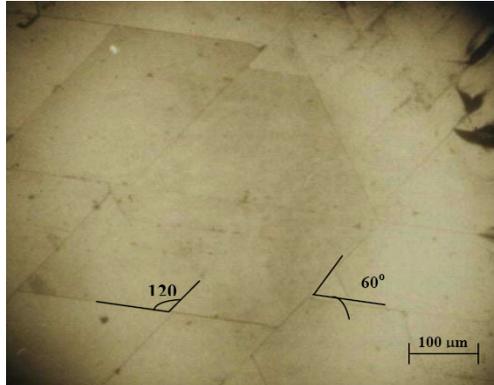
Energy density ( $\text{J} \cdot \text{cm}^{-2}$ )	5.92	11.34	16.8	18.4	21.1
Effective Spot Area ( $\text{cm}^2$ )	0.038	0.0167	0.0044	0.0038	0.0032

Topography of the treated region was studied with aid of optical microscope. Indium film with thickness of 500nm of 5N purity was deposited onto treated region using thermal resistive technique under pressure down  $10^{-6}$  Torr. The evaporation achieved through special mask, and ohmic behavior of this contact was extensively evaluated.

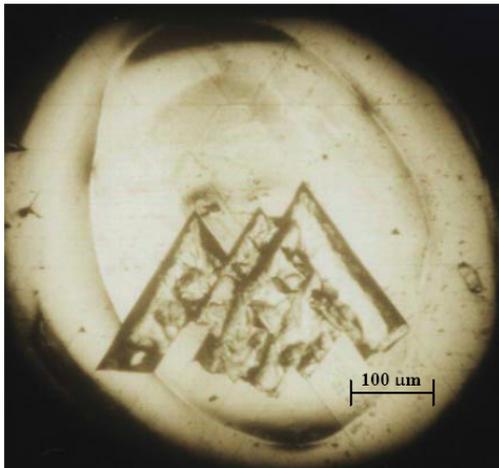
## 3. Results and discussion

The topography of Nd:YAG treated region is illustrated in the photographs of Fig. 1 (a), (b) and (c). Fig. 1 (a) shows a formation of crack with definite angles (60, 120) for laser energy densities ( $E_d$ ) up to  $11.34 \text{ J} \cdot \text{cm}^{-2}$ , these cracks are certainly formed due to thermal shocks. At  $16.8 \text{ J} \cdot \text{cm}^{-2}$  of laser density, dislocations are produced as shown in fig. (1-b) that mainly due to high cooling rate (quenching) of the hot surface, while protuberances, ripples, and concentric waves are occurred at laser densities greater than  $16.8 \text{ J} \cdot \text{cm}^{-2}$  as introduced in Fig. 1 (c) that are probably elucidated by the interaction between

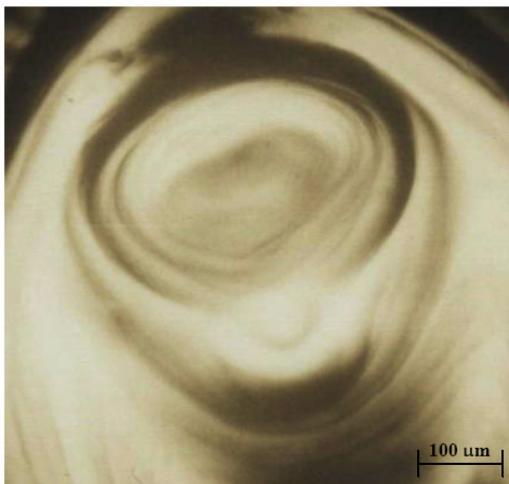
incident and scattered radiation by the aerosols in the atmosphere. The malformation of the laser treated surface is expected to act as interfacial traps region after metal deposition which in turn may enhance the ohmic behavior.



(a)



(b)



(c)

Fig. 1. Photographs of irradiated Si: (a)  $11.34 \text{ J/cm}^2$ , (b)  $16.8 \text{ J/cm}^2$ , and (c)  $18.4 \text{ J/cm}^2$ .

Fig. 2 demonstrates I-V characteristics in the forward and reverse bias voltages at room temperature of the In/Si contact of unirradiated surface. This figure shows poor ohmic contact behavior indicates that the resistance is non-linear. Also it exhibits that the forward current varies exponentially while the reverse current demonstrates soft breakdown and can be described by two distinct regions, the first region can be explained by a relation similar to that of equation:  $I \propto V$ , while the second is depicted by the equation:  $I \propto V^m$  where  $m < 1$ .

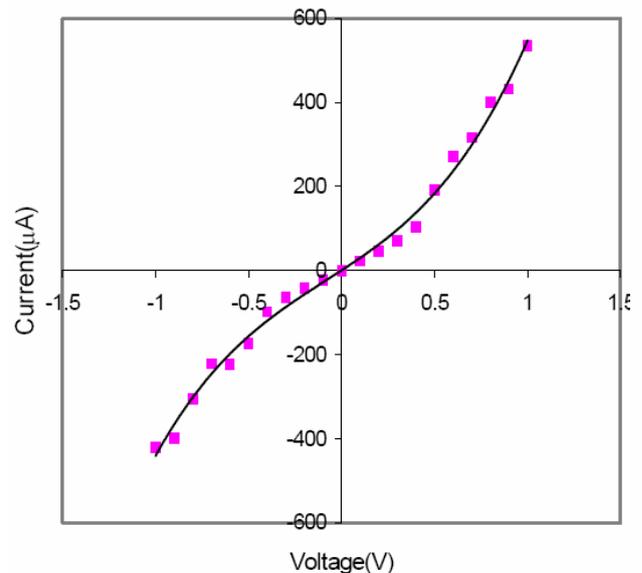


Fig. 2. I-V characteristics of In/Si contact before Si-irradiation.

Shown in Fig. 3 (a), (b), (c), (d), and e is the measured I-V characteristics in the forward and reverse bias for In/Si contact of Si-treated surface with different energy densities. The first three graphs of the figure (a, b, and c) illustrate clear ohmic behavior (i.e., the resistance is constant and voltage-independent). The figure also confirms that better ohmic behavior is obtained at energy densities greater than  $16.8 \text{ J/cm}^2$ , this can be explained as follow: at high energy densities the surface state density becomes more abundant due to increasing the defects, these surface states will act as interfacial states after electrode deposition which in turn, reduces the barrier height by adding tunneling mechanism to the junction. In addition, laser heating may lessen the segregated impurities and makes the treated region as a heavily doped region. The best results of ohmic behavior are registered at  $18.4 \text{ J/cm}^2$ . The rectification factor at a certain voltage (0.5, 1 V) is 1.02. This result is in full agreement with the results of other workers [9]. At  $21.1 \text{ J/cm}^2$ , ohmic behavior exhibits deterioration mostly due to surface damage which in turn affects on the intimate contact of the junction.

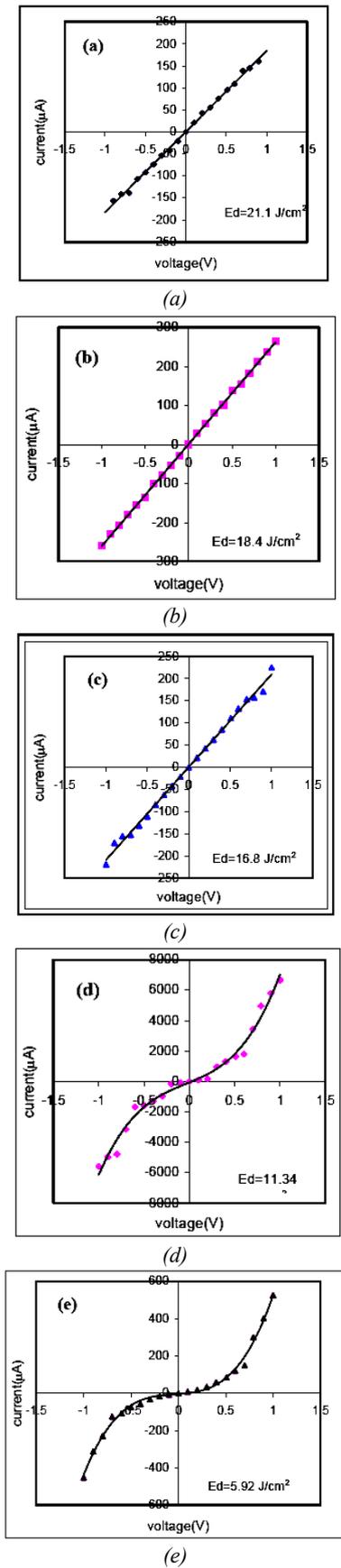


Fig. 3. I-V characteristics of In/n-Si contact irradiated with different energy densities at RT.

Sheet resistance likewise the type of electrical conductivity was measured using four-point probe technique. Conductivity type was maintained to be n-type before and after laser treatment indicated that the used laser energy is not high adequately to change the conductivity. The variation of sheet resistance with laser energy density is described in Fig. 4. Sheet resistance was raised from 0.46 Ω/sq (the as-received sheet resistance) to 1.55 Ω/sq after irradiation with 5.92 J.cm<sup>-2</sup> laser energy density, but it is diminished to a value smaller than its initial value, e.g. 0.11 Ω/Ń after irradiation with high laser energy density (21.1 J/cm<sup>2</sup>). The above mentioned can be interpreted as following: after laser irradiation, phase transformation is taken place and amorphous phase will be produced leading to increase sheet resistance. On the other side, increasing laser energy density will reduce the segregated impurities that are created previously during diffusion [10] and hence, will contribute in increasing doping concentration [4]. Consequently, sheet resistance will be decreased. Another observation can be caught from this figure that is at high laser energy densities (>11.34 J.cm<sup>-2</sup>) sheet resistance displays a steadiness which supports that there is no more segregated impurities that can be diffused [2].

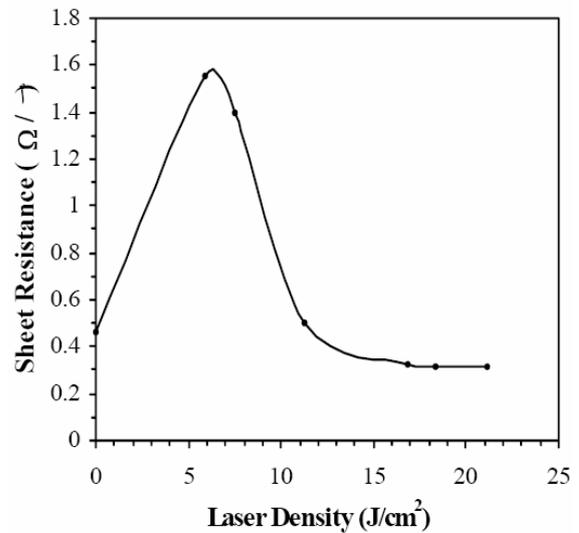
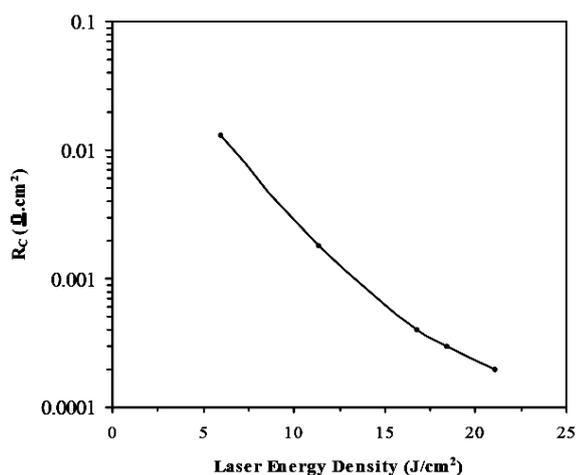


Fig. 4. Sheet resistance as a function of laser energy density.

Table 2 shows reverse saturation current ( $I_s$ ) and Schottky barrier height ( $\Phi_{Bn}$ ) that were extracted from the semi-log forward I-V curve (not found here). The increase of saturation current with respect to the increase laser energy density is undoubtedly because of the increment of interface states density. According to this result, decreasing in barrier height will be expected. Schottky barrier height exhibits a soft decrease with increasing energy density. Barrier decreasing is due to formation of nonalloyed ohmic contacts [4]. A 0.28 eV of barrier was obtained at 21.1 J.cm<sup>-2</sup> laser conditions, which gives fair agreement with theoretical considerations of best ohmic contacts.

Table 2. Influence of laser energy density on  $I_S$  and  $\Phi_{Bn}$ .

$E_d$ (J/cm <sup>2</sup> )	$I_S$ ( $\mu$ A)	$\Phi_{Bn}$ (eV)
5.92	4	0.31
11.34	20	0.32
16.8	50	0.30
18.4	90	0.29
21.1	200	0.28

Fig. 5. Specific contact resistance as a function of  $E_d$ .

Specific contact resistance ( $R_C$ ) describes the electrode resistance hence; it is calculated from  $\Phi_B$  that formerly determined. Fig. 5 demonstrates the variation of  $R_C$  with different laser conditions. The figure shows a sharp decrease of  $R_C$  with increase laser energy density. A significant decreasing in  $R$  for laser treated samples comparing with unirradiated samples. This decrease refers to the feasibility of laser technique among other techniques to produce good nonalloyed ohmic contacts. Ref. [11] is a comparable example whom achieved low specific contact resistance (about  $27 \times 10^{-4} \Omega.cm^2$ ) for contacts prepared by using T.L.M technique. By making a comprehensive comparison between these results and published results, one can deduce that Nd:YAG pulsed-laser surface treatment under optimum conditions is a candidate method to produce good ohmic contact.

#### 4. Conclusions

From what has been discussed above, one can conclude that Nd:YAG laser irradiation of n-Si surface facilitates the obtainment of ohmic contact with In-electrode. Near-unity rectification factor can be obtained at certain energy density of laser irradiation. Results of low specific contact resistance approve that this technique is a competitive as compared with conventional techniques. Irradiation of Si with KrF laser to produce ohmic contact is underway.

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