Ohmic Contacts Formation of Silicon Schottky Diodes by Screen Printing and Rapid Isothermal Processing

D. RATAKONDA,[1] R. SINGH,[2] L. VEDULA,[3] and S. NARAYANAN[4]

1.—Micron Technology, Inc., Boise, ID 83707-0006. 2.—Department of Electrical and Computer Engineering Materials Science and Engineering Program, Clemson University, Clemson, SC 29634-0915. 3.—Level One Communications, Sacaramento, CA 95827. 4.—Solarex (A business unit of Amoco Enron Solar), Frederick, MD 21703

Rapid isothermal processing based on incoherent radiation as the source of optical and thermal energy is playing a major role in flexible fast-cycle time integrated circuits manufacturing. In this paper, we present the dark and illuminated current-voltage characteristics of silicon Schottky barrier diodes where the ohmic contacts are formed by screen printing and rapid isothermal annealing. These results are compared with evaporated contacts followed by furnace annealing or rapid isothermal annealing. In this paper, we have shown that the ohmic contacts formed by screen printing and rapid isothermal annealing are compatible with the contacts formed by evaporation process. The processing time of the screen printed ohmic contacts is significantly lower than the contacts formed by evaporation process.

Key words: Cycle time, ohmic contacts, rapid isothermal processing (RIP), Schottky barrier diodes, screen printing

INTRODUCTION

Silicon Schottky barrier diodes are ideal for high frequency and fast-switching applications. Their low cut-in voltage makes them attractive for clamping and clipping applications.[1] The semiconductor industry is moving in a direction where manufacturing cost reduction is an important issue. Processing time is directly related to the manufacturing cost. As a short time processing technique, rapid isothermal processing (RIP),[2–7] based on incoherent radiation as a source of optical and thermal energy has been used successfully for the fabrication of various semiconductor devices. Generally, ohmic contacts are formed by evaporation or sputtering followed by furnace annealing. Screen printing is a cost-effective film deposition technique where a paste containing the desired material is screen printed by conventional methods onto a suitable substrate to define device patterns.[8] Subsequently, the substrate is fired under appropriate conditions of time and temperature to yield components bonded to the substrate. In this paper, for the first time, we report the dark and illuminated current-voltage (I-V) characteristics of Schottky barrier diodes where the metal ohmic contacts were formed by screen printing followed by rapid isothermal annealing. Surface roughness measurements were done using atomic force microscopy (AFM). For comparison, we have also reported the dark and illuminated I-V characteristics and AFM surface roughness measurements of Schottky barrier diodes where ohmic contacts are formed by evaporating aluminum contacts and followed by rapid isothermal annealing or furnace annealing.

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EXPERIMENTAL

Czochralski single side polished p-type <100> silicon wafers of 1–10 ohm-cm resistivity and one inch diameter were used in this study. Schottky barrier diodes were formed by making an ohmic contact on the back side of the wafers and depositing an aluminum barrier layer on the polished side of the wafers. Ohmic contacts were formed by two different deposition methods. In one case, screen printing of Ag/Al 3398 paste[9] (purchased from Ferroelectronic materials division) was done by using a manual screen printer.[10] In the other case, vacuum evaporation of aluminum contacts was carried out through a shadow mask. For both cases, the annealing was done using a home-built programmable rapid isothermal processor which is equipped with top and bottom banks consisting of tungsten halogen lamps. The lamp configuration used in the RIP system is shown in Fig. 1. The two top lamp banks are fixed at an angle of about 45°. The temperature of the sample is measured by a chromel-alumel K-type thermocouple. The temperature is monitored and controlled by Micrihost dimension control software. The software has the capability to sense the temperature from the system and adjust the power of the lamps in a closed loop feedback control for obtaining an accurate temperature profile. The annealing of screen printed paste (case A) was done in air with a ramp up rate of 10°C/s up to a temperature of 720°C and then cooled down to 225°C at a rate of 10°C/s and then cooled down to room temperature. The vacuum evaporated aluminum contacts (case B) were annealed at atmospheric pressure in nitrogen ambient with a ramp up rate of 14°C/s and holding at 475°C for 2 min and then cooling down to room temperature. For comparison purposes, Schottky barrier diodes were also formed in both cases A and B where furnace annealing was used in place of rapid isothermal annealing. The screen printed contacts are annealed in a conventional furnace at 680°C for 30 min. The vacuum evaporated aluminum contact is annealed in a conventional furnace at 450°C for 30 min in nitrogen ambient. An uncalibrated light source is used for the measurement of illuminated I-V characteristics. Both dark and illuminated I-V characteristics are obtained using a HP 4145 A semiconductor parameter analyzer. We have used atomic force microscopy for the measurement of surface roughness of ohmic contacts formed by different processing conditions.

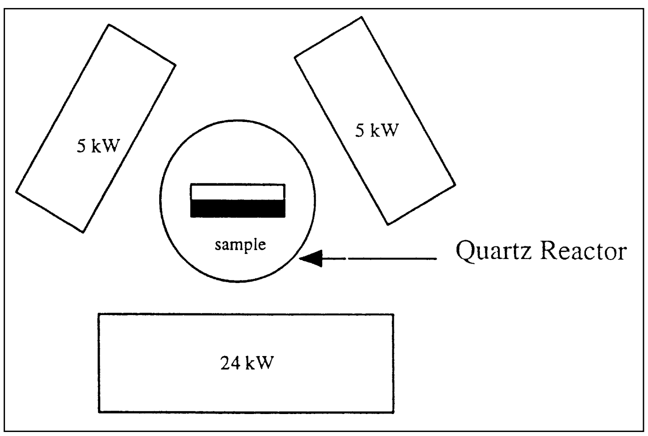

Fig. 1. Lamp configuration used for rapid isothermal annealing of the ohmic contacts.

RESULTS AND DISCUSSION

The dark I-V characteristics of various Schottky barrier diodes were analyzed to find the values of leakage current densities J_0, ideality factor n, and the value of series resistance R_s. The area of the diodes was 0.785 cm^2. The illuminated I-V characteristics were analyzed to find the values of open circuit voltage V_{oc}, short circuit current densities J_{sc}, and the fill

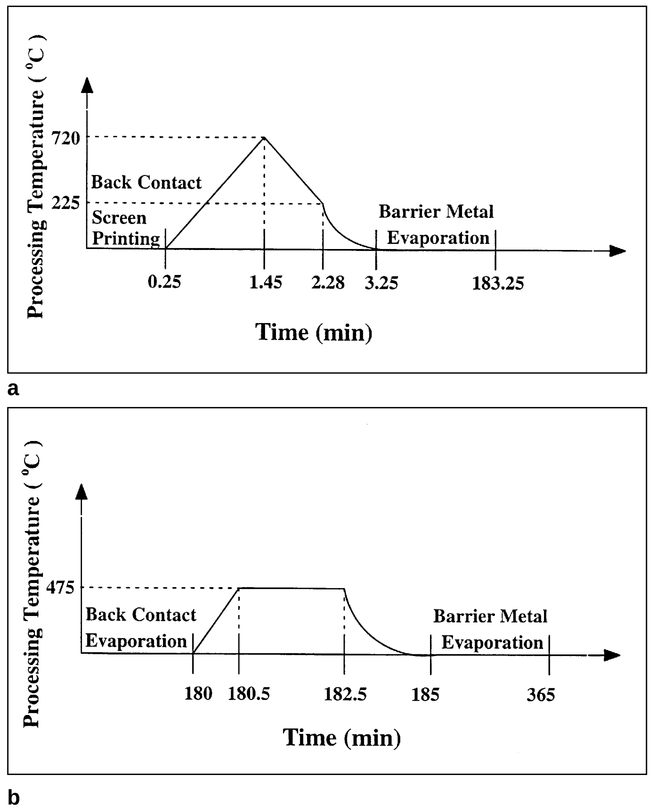

Fig. 2. Cycle time of rapid isothermal annealed, (a) screen printed ohmic contact, and (b) evaporated ohmic contacts.

Table I. Electrical Characterstics of Schottky Barrier Diodes: (A) Ag/Al Screen Printed Ohmic Contacts (B) Al Evaporated Contacts

Sample	n		R_s (Ω)		J_o (A/cm^2)		V_{oc} (V)		J_{sc} (μA, cm^2)		FF	
No.	A	B	A	B	A	B	A	B	A	B	A	B
RIP #1	1.37	1.35	1.9	2	1.2E-9	1.15E–9	0.45	0.45	204	217	0.63	0.64
RIP #2	1.2	1.4	1.9	2.2	1.15E-9	1.27E–9	0.44	0.43	160	178	0.66	0.65
RIP #3	1.42	1.42	2	2.1	1.27E-9	1.27E–9	0.44	0.43	166	155	0.62	0.63
RIP #4	1.4	1.42	2	1.8	2.68E-9	1.27E–9	0.42	0.42	108	106	0.6	0.63
RIP #5	1.34	1.33	2	2.3	1.48E-9	1.27E–9	0.43	0.44	163	162	0.64	0.61
RIP #6	1.37	1.4	2	2	1.27E-9	1.25E–9	0.44	0.44	191	178	0.64	0.64
CFP	1.45	1.4	105	95	1.27E-9	1.17E–9	0.44	0.45	163	161	0.63	0.62

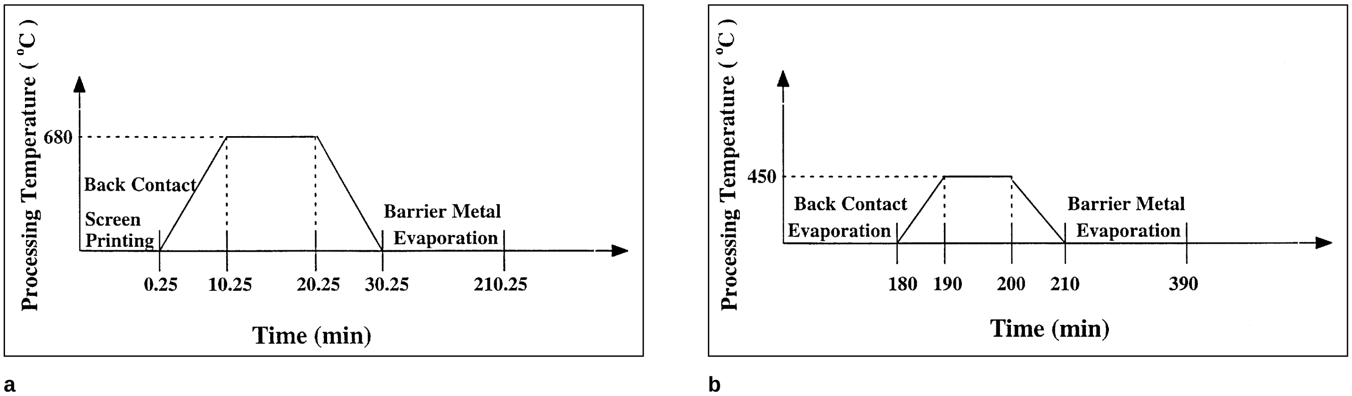

Fig. 3. Cycle time of the conventional furnace annealed, (a) screen printed ohmic contact, and (b) evaporated ohmic contacts.

factor FF. These results are shown in Table I. Cases A and B represent screen printed and vacuum evaporated aluminum contacts, respectively. An examination of Table I shows that the performance of screen printed contacts is compatible to that of the evaporated contacts. The total processing cycle time of the Schottky diodes for the rapid isothermal annealing and furnace annealing cases are shown in Fig. 2 and Fig. 3, respectively. An examination of Fig. 2 shows that in case of RIP, the use of screen printing process reduces the cycle time by almost 100%. Similarly, we can see from Fig. 3 that in the case of furnace processing, the use of screen printing process reduces the cycle time by almost 90%. As compared to contacts formed by evaporation and furnace annealing, the use of screen printing and rapid isothermal annealing reduces the cycle time by about 115%. Average surface roughness values were obtained from AFM micrographs. The average surface roughness of evaporated and screen printed contacts obtained are 923 and 185 nm, respectively. For furnace annealing, average surface roughness of evaporated and screen printed contacts are 938 and 209 nm, respectively.

The results presented in this paper clearly demonstrate that the use of screen printing and rapid isothermal annealing provide ohmic contacts with lower surface roughness and reduced cycle time.

CONCLUSION

In this paper, we have demonstrated that the use of screen printing and rapid isothermal annealing in the ohmic contact formation of Schottky barrier diodes significantly reduce the total process time. The surface roughness of contacts formed by this method is lower than that of evaporated contacts. This technique offers a tremendous potential for the reduction of processing time in the case of large area devices such as solar cells and flat panel displays.

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