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LASER FORMATION OF Pt-Si SCHOTTKY BARRIERS ON SILICON

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135 nsec pulses of $\lambda = 1.06\mu m$ light from a Nd: YAG laser have been used to form Schottky barriers by irradiation of a 500Å thick metal film on n-type silicon. Large area barriers were fabricated by over-lapping individual $30\mu m$ diameter laser pulses of from 4 to 12 J/cm^2. The barrier height was 0.73 ± 0.03 V, independent of the laser power. The barrier quality, as assessed by measurement of the forward current characteristic, decreased with laser power to a value of $n = 1.5$ at 12 J/cm^2.

Keywords: Laser annealing Schottky barriers Pt-Si

Introduction

The formation of surface layers of metal-silicon intermetallic compounds via solid state reaction is a common method for the production of Schottky barriers or ohmic contacts on silicon.(1) The equiatomic PtSi intermetallic produced by reaction of thin Pt films on silicon forms an ohmic contact to n^+ and p-type silicon and a Schottky barrier of 0.82 to 0.85 eV height on lightly doped ($\sim 10^{17} cm^{-3}$) n-type material.(2) Our aim here is to report that Pt-Si surface alloy layers formed by laser processing also form Schottky barriers on n-type silicon. It has also been established(3) that laser processed Pt-Si alloy layers form ohmic contacts to p-type silicon, and that p-n/PtSi junction diodes may be fabri-

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cated by laser processing a Pt coated, p-type crystal that has been implanted with As ions. Laser processing thus offers an alternative to standard furnace processing for the production of these common contact structures.

Following the revelation[4] that pulsed laser light could be employed to anneal ion implantation damage in silicon surface layers, we discovered that the Pt-Si reaction could also be stimulated by laser irradiation.[5] The path of the reaction, however, was found to be quite different from that followed during furnace annealing. Pulsed laser irradiation at intensity levels below that required to melt silicon produces a thin film of molten Pt-Si alloy whose thickness and composition depend linearly upon the laser pulse energy density.[5] Sodification of this molten layer at the high rates common to laser processing[6] yields a polyphase solid layer of extremely fine (~100Å) grain size that is uniform in composition and thickness. The composition of the film depends upon the quantity of silicon that is consumed by the molten layer. Alloy compositions in the range from Pt_2Si to $PtSi_{10}$ may be reproducibly formed, and the phase mixture produced by laser processing depends upon this composition. Because these surface films, which may be formed by local, patterned laser processing, exhibit smooth surface morphology and good dimensional stability, their electrical properties are of interest.

Experimental

Arsenic doped silicon wafers of 0.5 Ω cm resistivity were selected as substrates, and were processed to produce an n^+ layer on the back surface. A 3000Å thick thermal oxide was grown on the polished front surface. An array of circular windows of 0.05 cm diameter was then photolithographically patterned and etched into the SiO_2 layer, and 500Å of Pt was deposited in an oil free vacuum system onto the wafer surface. The Pt coated crystals were then irradiated with 135 nsec pulses of $\lambda = 1.06\mu m$ light from a Nd:YAG laser that was operated in the TEM_{00} mode at a pulse repetition rate of 11.5 kHz. Each pulse was focused to a 1/e diameter of 30μm, and large areas were processed by translating the laser beam 8μm between successive pulses to produce an array of overlapping pulse spots.

The Pt film covering the oxidized silicon was melted and agglomerated into discrete, 1-5μm spheres at all power levels sufficient to induce the Pt-Si reaction. The individual, circular unoxidized windows within which the reaction occurred were consequently isolated from one another and electrical measurements were performed without further processing.

Electrical Properties

The occurrence of laser induced reaction of Pt and Si is accompanied by a change in surface luster and can easily be established visually. For all laser power levels at which the reaction occurred, Schottky diode behavior was observed. Representative I-V characteristics of diodes produced at several laser power levels are plotted in Fig. 1.

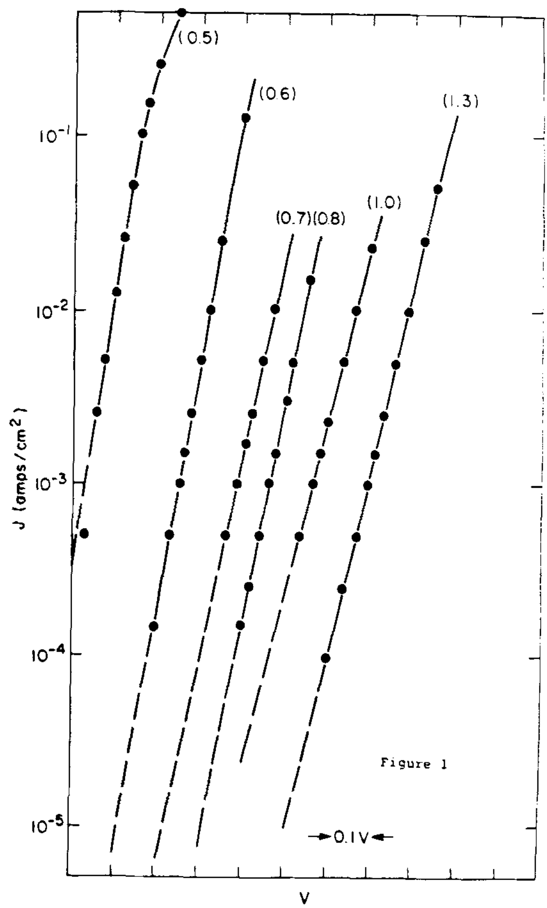

Fig. 1 The forward bias characteristics of laser processed Pt-Si Schottky barriers. Each curve has been offset 0.1V on the horizontal axis for clarity. The number in parenthesis is the average laser power used in diode formation.

The saturation current, J_s, determined by linear extrapolation of the data in Fig. 1 to zero volts is listed in Table I, together with the barrier height that may be inferred[7] from it. This table illustrates that the barrier heights are independent of laser power over the range examined, which spans the power levels of practical interest. At 4.7 J/cm^2 (0.5 W avg. power) for example, no visible evidence for reaction was observed. The barrier behavior shown in Fig. 1 for this pulse energy consequently differs greatly from those produced at higher power, and probably reflects the properties of the Pt/Si contact. At 12.3 J/cm^2, the surface of the reacted material was visibly roughened, the individual laser spots being easily discerned. Over the range from 5.6 to 12.3 J/cm^2, the mean alloy layer composition produced in similar films varied linearly with pulse energy from ~ PtSi to $PtSi_{10}$.

TABLE I

PROPERTIES OF LASER PROCESSED SCHOTTKY DIODES

Laser Power		*Laser Energy*	J_s	ϕ_B	n
avg.	pulse		(amp/cm^2)	(V)	
0.5W	35MW/cm^2	4.7J/cm^2	2.85×10^{-4}	0.63	1.0
0.6W	42MW/cm^2	5.6J/cm^2	6.1×10^{-6}	0.73	1.149
0.7W	49MW/cm^2	6.6J/cm^2	6.6×10^{-6}	0.735	1.42
0.8W	56MW/cm^2	7.6J/cm^2	6.9×10^{-6}	0.73	1.24
1.0W	70MW/cm^2	9.45J/cm^2	2.3×10^{-5}	0.7	1.66
1.3W	91MW/cm^2	12.3J/cm^2	8.9×10^{-6}	0.725	1.57

The diode quality as assessed by the slope, $n = qV/kT\ln(J)$, of the data shown in Fig. 1 decreases with increasing laser power as shown in Table I. Clearly, optimum diodes are produced at laser power levels just sufficient to induce the reaction. This conclusion is also reflected in the data of Fig. 2, in which the reverse bias characteristics of the diodes have been plotted.

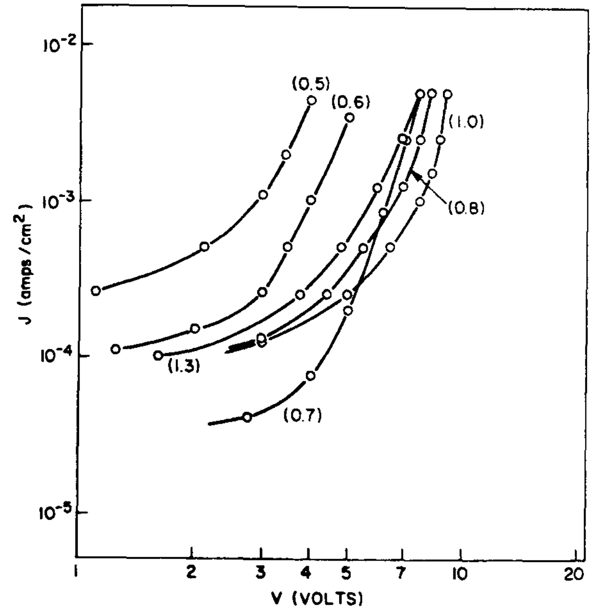

Fig. 2 The reverse bias characteristics of the diodes shown in Fig. 1.

Although we assign no specific significance to the values of breakdown voltage and leakage current displayed in Fig. 2, the curves are representative of diodes produced by irradiation of Pt films over oxide windows, and do indicate a minimum in leakage current for the diode produced at 6.6 J/cm^2 (0.7W avg. power).

Conclusions

These preliminary results indicate that Schottky diodes of reproductible barrier height may be fabricated by laser irradiation of thin Pt films on n-type silicon. The barrier height is insensitive to laser power while diode quality is degraded by processing at pulse energies above those required to form the surface alloy.

In a separate development,[3] we have recently learned that As implants beneath Pt surface layers are driven before the molten surface alloy during laser processing. In p-type material, this results in As activation and the formation of a p-n junction below the surface alloy, which forms an ohmic contact to the n^+ region created by the As dopant. This result suggests that the barrier height of laser processed Pt-Si surface alloys may be modified by implantation of suitable n-type dopants prior to processing as is current practice[8] for furnace annealed barriers. Laser processing of Pt coated silicon thus appears to offer great flexibility for the formation of ohmic contacts and Schottky barriers on silicon, and offers the advantage that processing need not be performed over the whole of a given device.

Acknowledgment

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