論文 87-24-6-7

The Effect of Sheet Resistance of Polysilicon Resistor with Contact Implantation and Metal Deposition

(Contact 이온주입과 Metal 증착이 다결정 실리콘저항의 면저항에 미치는 영향)

朴 鍾 泰,* 崔 民 成,** 李 文 基,*** 金 鳳 烈***

(Jong Tae Park, Min Sung Choi, Moon Key Lee and Bong Ryul Kim)

要 約

높은 면저항(Rs, 350Ω/□)을 갖는 다결정 실리콘 저항을 바이폴라 공정조건에서 boron 이온주입 방법에 의하여 제작하였다. 본 실험에서는 contact 영역에 boron을 이온주입한 경우와 주입하지 않은 경우의 Rs 변화와 전자총 방법으로 Metal을 증착시킨 경우와 그렇지 않은 경우의 Rs 변화를 연구하였다.

결과로 부터 contact 영역에 이온주입한 경우가 주입하지 않은 경우보다 Rs 값이 크고 스파터링 방법으로 Metal을 증착시켰을 때 Rs 변화가 적었다.

Abstract

High value sheet resistance (Rs, 350Ω/□-80 KΩ/□) boron implanted polysilicon resistors were fabricated under process condition compatible with bipolar integrated circuits fabrication. This paper includes the the effect of contact ion implantation on Rs and the effect of electron gun (e-gun) deposition vs. non e-gun evaporated metal contacts on the Rs. From results, we observed that the contact ion implanted samples showed higher Rs value than those without contact ion implantation. Also, it was shown that there is noticeable amount of Rs degradation for e-gun samples, while sputtered samples expressed little Rs degradation after PtSi was formed.

I. Introduction

Polysilicon has been widely used for the gate materials of MOSFET, the load resistor of MOS digital IC's, the load resistor of static MOS RAM cells, and the resistor of bipolar IC's. Polysilicon resistor has the advantage of not only decreasing the power consumption but increasing both chip density and performance. Its usage is greatly restricted, however, by some major problems of reproducibility associated with the polycrystalline nature of the material.

One of the problem is the great sensitivity of Rs to both doping concen tration and contact ion implantation (1). For a simple metal (e.g. Al), deposited directly onto a clean silicon surface, Shannon (2) and Andrew et al.

*正會員, 仁川大學 電子工學科

(Dept. of Elec. Eng., Incheon Univ.)

**正會員, 金星半導體株式會社

(GoldStar Semiconductor Ltd, R&D)

***正會員, 延世大學校 電子工學科

(Dept. of Elec. Eng., Yonsei Univ.)

接受日字：1986年 6月 25日

(3) have shown that the effective barrier height between metal and silicon can be modified by a shallow surface implant, the peak of which is located at the metal-silicon surface interfaces. The ion dose of contact implant is critical in determining the device properties in that the surface implant has to be completely depleted when no external voltage is applied in order to ensure minimum leakage under reverse condition. Yet, there is no study on the effect of contact implantation of polysilicon resistor. This paper shows the effect of contact implantation.

Another is Rs degradation after the contact metal which is deposited by e-gun evaporation, In recent years, silicide contact have emerged as highly promising candidates for silicon VLSI application because of extremely clean surface and good thermal stability(4). The advantage of silicide formation is the most reliable and reproducible Schottky barrier and that silicide formation automatically cleans the interface, thus avoiding the variability in contact properties that may otherwise occur when the surface is contaminated or imperfect. In this respect, PtSi has been most useful silicide (5).

In this paper, the controllability of the sheet resistance of boron implanted polysilicon resistor with the effect of contact implantation and the effect of contact metal deposition method for PtSi and Al are discussed.

II. Experimental procedures

The flow of experimental procedures is shown figure 1. A 3700 Å of thermal oxide was grown on p-type silicon wafer (10-20Ω-cm) at 1000 °C, 50 minutes. After LPCVD (low pressure chemical vapor deposition) polysilicon was deposited (3000 or 4000 Å) by silane decomposition at 625°C, a thermal cap oxide (400 Å) was grown on top of the polysilicon at 900°C, 45 minute. Boron was implanted for polysilicon resistor at 50-75 keV, 1.8E14-4.4E14 cm^{-2}. Boron was selected because its segregation at the grain boundaries was reported to be small compared to phosphorus or arsenic (6). The anneal was done in the range of 800-1100°C for 64 or 81 minutes in N_2 ambient. Some of these conditions

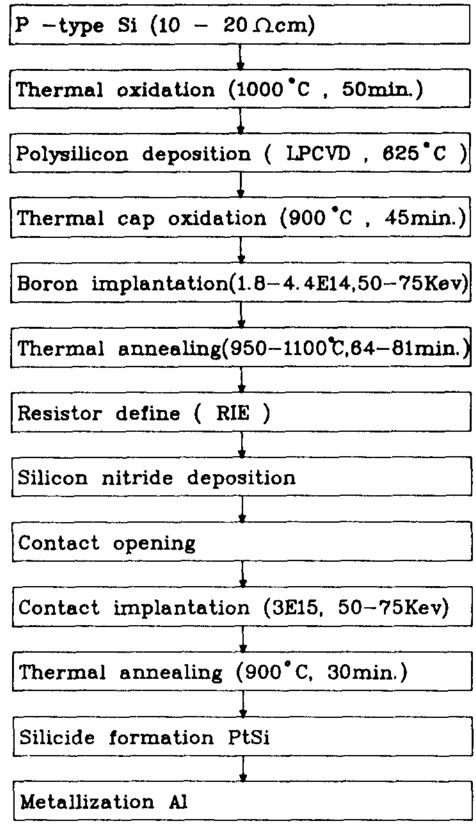

Fig. 1. The flow chart of sample preparation.

simulated the base and emitter anneal heat cycle of an actual bipolar process. The resistor was defined photolithography and reactive ion etching (RIE) of oxide and polysilicon. CVD silicon nitride was deposited and resistor contact area was defined. Some wafers received both a contact ion implant with boron and extra activation anneal at 900°C for 30 minutes in N_2 ambient. Immediately after the contact ion implantation was done, the contact area was opened and PtSi was formed as a contact metallurgy. The structure of polysilicon resistor is shown in Figure 2.

Al-4%-Cu was deposited as the conducting metal after which a further anneal was done at 400°C for 1-2 hour in N_2 ambient. The test vehicle had a four-point probe structure and different resistor sizes. Rs was measured at two current levels (25 μA, 50 μA) to measure the voltage coefficient of resistance (VCR). VCR was zero as expected. Twelve to twenty-four sites of each wafer were measured for Rs across the wafer at 25°C and 125°C.

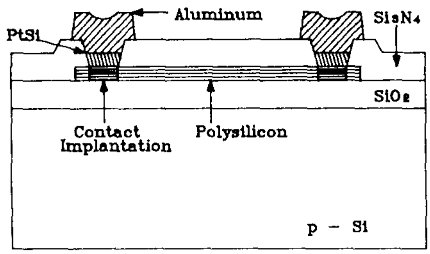

Fig. 2. Schematic cross section of a polysilicon resistor.

III. Experimental results

1. *Effect of Contact Ion Implantation on Rs*

In section II, it was explained that a wafer split was made within a job so that some wafers received the contact ion implantation (I/I) with boron (dosage 3 E15/cm^2) and extra anneal at 900°C for30 minutes to achieve a good ohmic contact after metallizing the resistor. A flat profile of boron concentration across the polysilicon film was assumed after anneal and was verified by secondary ion mass spectroscopy (SIMS); the doping concentration was calculated from the thickness and ion implantation dosages (1). Table 1 contains the summary of the comparisons between contact ion implanted and non-contact ion implanted samples. Figure 3 displays Rs values for samples without contact implantation vs. Rs value of those with contact implantation. It is also demonstrated in this figure that all the contact ion implanted samples show higher Rs values than those without contact ion implantation, except those at low Rs values. This effect is more pronounced for the samples of 4000 Å thickness than those of 3000 Å. In figure 3, the ratio of Rs (contact I/I) to Rs (non-contact I/I) ranges approximately between 1.0-1.20 and 1.0 -2.0 for 3000 Å and 4000 Å films, respectively for the samples of this work.

2. *Effect of Electron-Gun Evaporated Metalization on Rs*

It was explained earlier that PtSi was formed at the contact area just before Al/Cu was deposited for electrical connection to the polysilicon resistor. Silicide films are commonly used in bipolar technology as barrier metallurgy to prevent the interaction of Al layers with polysilicon (7). Two methods of platinum deposition were used: electron-gun

Table 1. Effect of contact ion implant on R.

JOB #	WAFER #		R_S(KΩ/□)		POLYSI THICKNESS (A°)	ANNEAL TEMP (℃)
	CONTACT	NON-CONTACT	CONTACT	NON-CNOTACT		
0707	7	8	81.6	67.6	3000	800
0712	11 - 12	13	12.3	10.2	3000	1000
0632	5, 6	8	11.4	10.0	3000	1000
0715	12	13	11.1	9.0	3000	1100
0627	5 - 6	7 - 8	10.0	9.9	3000	1000
4413	13 - 15	20	7.1	6.0	3000	1000
0627	12, 14 - 15	16 - 17	6.4	6.5	3000	1000
0715	17	18	2.7	2.6	3000	1100
0415	2	3	1.82	1.65	3000	1000
0307	6	7 - 8	1.72	1.55	3000	1000
0706	7	8	1.0	.97	3000	1100
0706	12	14	.71	.69	3000	800
0706	17	18	.350	.346	3000	1100
0707	2	3	26.6	13.6	4000	950
0706	2	3	7.9	4.7	4000	950
0307	11 - 12	14 - 15	1.03	.8	4000	950
0712	1 - 2	3	.34	.35	4000	950

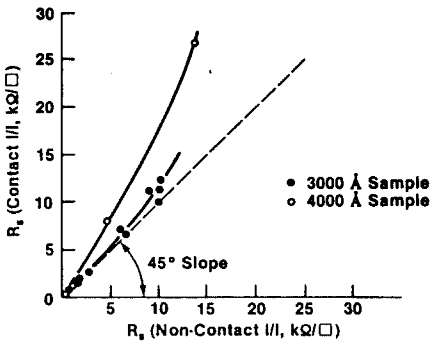

Fig. 3. Effect of contact ion implantation on R_S.

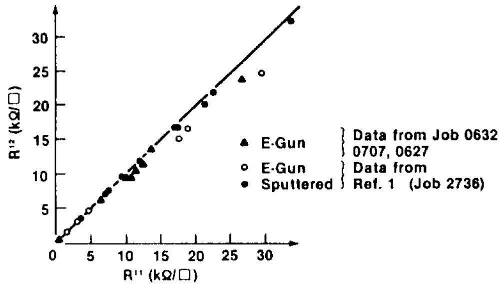

Fig. 4. Effect of E-Gun evaporated Vs sputtered platinum deposition.

evaporated and sputtered platinum. After Pt was deposited (500 Å), the wafer were sintered at 550 °C for 20 minutes to form the silicide.

Fig. 4. displays Rs^{11} vs. Rs^{12} where Rs^{11} and Rs^{12}; the Rs of diferent resistors measured before Pt deposition and after PtSi was formed, respectively. In this figure, we expect that all the data points sit on the 45 straight line. However, it shows that there is a noticeable amounts of Rs degradation for the e-gun samples after the PtSi film were formed. This effect was apparent for the Rs values greater than 10 KΩ/□. However, sputtered samples experienced little Rs degradation after PtSi was formed. The effect of e-gun evaporated vs. resistant heat evaporated aluminum deposition on the Rs degradation is more striking; it is demonstrated in Table 2. Some typical data in this table are plotted in fig. 5, where Rs

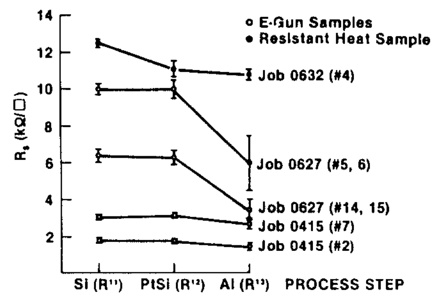

Fig. 5. Effect of E-Gun metal deposition on R_S.

value are shown as measured at different process steps described in Table 2. It is clearly seen that all e-gun samples except for resistant heat aluminum experienced severe Rs degradation not only in average Rs value but also in its spread (standard deviation) around the mean. It is also noticed in fig. 5. that Rs

Table 2. Effect of metal deposition (Al/Cu) method on sheet resistance.

JOB #	WAF #	$R_S^{11} \pm \sigma$ (KΩ/□)	$R_S^{12} \pm \sigma$ (KΩ/□)	$R_S^{13} \pm \sigma$ (KΩ/□)	DEPOSITION METHOD
0627	5, 6	10.0±0.3	10.1± .48	6.0±1.48	e-gum
0627	14, 15	6.4±0.17	6.3±0.36	3.50±0.56	e-gun
0632	1	12.5±0.24	11.4±0.20	7.1±0.61	e-gun
0632	5	11.4±0.16	10.2±0.18	6.6±0.56	e-gun
0632	6		10.4±0.13	7.5±0.15	e-gun
0632	4	12.5±0.2	11.1±0.4	10.8±0.31	Resist. Heat
0632	13	10.1±0.13	9.4±0.13	9.4±0.10	Resist. Heat
0415	2	1.8±0.02	1.8±0.02	1.5±0.14	e-gun
0415	7	3.1±0.05	3.2±0.05	2.7±0.13	e-gun

σ : Standard Deviation
R^{11} : R_S measured before Pt was deposited
R^{12} : R_S measured after PtSi was formed
R^{13} : R_S measured after Al/Cu deposition and 1 hour sintering at 400℃

degradation tends to be higher for the higher Rs. The minor shift between R^{11} and R^{12} is ascribed to the e-gun evaporated platinum deposition explained above. (All the wafers in table 2. and in fig. 5. had the e-gun platinum deposition.)

IV. Discussions

1. Effect of Contacts Ion Implantation

In figure. 3, it was shown that the slope Rs (contact I/I) vs Rs (noncontact I/I) plot is increasing as Rs values increase. The only difference in process conditions between these wafers was that contact ion implanted samples received an extra anneal at 900°C for 30 minutes in addition to the resistor anneal done at temperature in the range of 950°C-1100°C before contact ion implantation was made. We hardly expect that there would be any change in grain size or in grain boundary carrier trapping density for the contact ion implanted wafers by an additional anneal at a lower temperature than the previous anneal. If that is true, the slope in fig. 3. should have been a 45 degree straight line regardless of the film thickness. One possible explain for the deviation from the expected would be due to the grain boundary segregation of boron atoms caused during the extra anneal at 900 °C, which would inactive them electrically and therefore reduce the total effective carrier concentration. Mandurah et al. (6) measured the electrical carrier concentration for boron doped (2E19 atoms/cm^3) polysilicon film after different annealing steps. They reported no appreciable tendency for the boron dopant atoms to segregate to the grain boundaries. However, their data plot revealed a slight indication of boron segregation during the low temperature anneal (800-900 °C) after inital anneal at 1000°C even though the tendency was close to the measurement error. For the wafers of high doping concentration (greater than 2E19 atoms/cm^3) in fig. 3, the deviation of the data point from the 45-degree straight line was minimal (see the data points of Rs below 2kΩ/□). This can be interpreted as negligible boron segregation at the grain boundaries compared with the total effective carrier concentration for high doping. This assumption is justified by the fact that the deviation from the 45-degree slope in fig. 3. becomes larger as Rs increased (or doping concentration decrease). Recent investigators (8) observed that there is preferential segregation of boron atoms into polysilicon films when boron was outdiffused at 900°C from the single crystal silicon source into polysilicon film. They explained this effect by the pile-up of boron dopant atoms at the polysilicon grain boundaries. The reason why thicker films (4000 Å) show larger deviation from the 45-degree line and higher sensitivity to the Rs value than the thinner samples (300 Å) may be explained as follows (see figure 3); after the same amount of initial at 1000°C or 950°C it is expected that the thicker film requires a smaller amount of doping concentration than the thinner film to maintain the same Rs. If boron segregation occurs during the subsequent heat cycle at low temperature, it is reasonable to assume that the effect on the net carrier concentration (or Rs) will be higher for the thicker film, which has lower carrier concentration from the start. This is true only if the carrier mobility is not changed by the subsequent anneal. It means that grain boundary trapping properties are not modified significantly by the subsequent annealing since mobility is a strong function of the grain boundary It seems that assumption is valid according to the results in fig. 3.

2. Effect of Electron-Gun Evaporated metallization on Rs

It is a known fact that a positive space charge can be induced in insulating films (silicon dioxide, silicon nitride) from exposure to ionizing radiation such as x-ray or electron radiation (9). The charge level at the SiO_2 was measured for both e-gun-evaporated and resistant-heat-deposited samples by capacitancevoltage techniques for MOS (metal-oxidesemiconductor) structures. Wafers with e-gun metal showed higher level of charge (3E11/cm^2) than non-e-gun samples (1.0E11/cm^2). If the Rs degradation was caused by charges, they can gradually be annealed at above 400 °C. However, wafers prepared using the e-gun did not show any sign of improvement even after 3 hours of extended anneal at

400 °C. The x-ray radiation associated with the e-gun metal deposition is thought to be the possible reason for the Rs degradation. If the grain boundary characteristics of the resistor is somehow modified by the interaction between the radiation and resistor body it is possible to explain this phenomenon. This explanation is consistent with the fact that the Rs shift was larger as Rs increases (see table 2), i.e., Rs becomes more sensitive to the grain boundary characteristics at lower doping concentration where grain boundaries are less saturated. However, further work is required to understand the exact mechanism of Rs degradation. The more severe Rs degradation by aluminum deposition (10,000 Å) than the platinum deposition (450Å) is probably due to the difference in the amount of radiation dose they received during the deposition.

V. Conclusion

Boron ion implanted polysilicon resistors (350Ω/□- 80KΩ/□) were fabricated under conditins compatible with bipolar integrated circuits fabrication. The controllability of the sheet resistance of boron implanted polysilicon resistors with the effect of contact ion implantation and the effect of contact metal deposition method for PtSi and Al. From the results, the ratio of Rs (contact I/I) to Rs (non contact I/I) is approximately between 1.0-1.20 and 1.0-2.0 for 300 Å and 4000 Å film , respectively for the samples. Severe Rs degradation was experienced after the contact metal (Al/Cu) was deposited by e-gun evaporation while there was negligible Rs shift after resistant-heat deposition. X-ray radiation generated during e-gun metal deposition and its interaction with the polysilicon resistor is thought to be the cause of the shift.

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