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Hydrogenation Effects on the Specific Contact Resistivity of Al(1%Si) and TiSi₂ Contact to the Polysilicon

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The hydrogenation effects on the specific contact resistivity of Al and TiSi₂ contact to polysilicon is investigated by a modified vertical Kelvin test resistor structure. It is seen that ρ_c decreased after the hydrogenation treatments and more uniformity properties of ρ_c for metal contacts to polysilicon can be achieved than those of the un-hydrogenation samples. From the results of Hall measurements, the mechanisms of the improvement on ρ_c by the hydrogenation are not caused by the change of the effective carrier concentration but may be caused by the increase of mobility which represents the defect states located within grain boundraries and interfaces of polysilicon are reduced by the hydrogen passivation.

1.INTRODUCTION

Polysilicon deposited by the low-pressure chemical vapor deposition technique has been widely investigated due to its excellent compatibility with monolithic silicon technology. However, for polysilicon, its electrical properties are strongly affected by its microstructure such as the grain size, the doping material and concentrations, the grain boundaries etc. Compared to the single-crystal silicon, due to the large number of defect states at grain boundaries, it suffers a lower carrier mobility, a lower effective carrier concentration, and a higher

contact resistance to metals.¹⁾ It is well know that hydrogen is electrical active in silicon. It has been observed that hydrogen in silicon passivates shallow acceptors, donors, point defects, and dangling bonds²⁾. In recent years, studies^{3,4)} have been made to implant hydrogen into polysilicon to passivate grain boundary traps to improve its electrical properties. After hydrogen implantation and subsequent low temperature sintering, hydrogen moves to the grain boundaries and interact with defects to reduce the effectiveness of the grain boundary traps and the interface states. In this paper, the hydrogen passivation effect on the specific contact resistivity, ρ_c , of Al(1%Si) and TiSi₂ contacts to polysilicon is investigated. In the study, a modified vertical Kelvin resistor structure⁵⁾ which gives a more precise measurement on ρ_c was used.

2.EXPERIMENTS

The modified Kelvin resistor structure is shown in Fig.1(a)-(d) in terms of its fabrication steps. Fig.1(e) is the top planar view. The polysilicon

resistor is made on a SiO_2 layer for which a contacting hole is opened to make the polysilicon resistor to contact with the substrate. Current is forced to flow from terminal 1 or 2 toward the substrate and the voltage drop across the metal/poly—Si contact can be measured from either at terminal 1 or 2 to terminal 3 or 4 and 5 or 6.



Fig.1 Cross-sectional and top views of the fabricating process for measuring $\rho_{\rm C}$.

In addition, Van-der-Pauw configured samples made on the polysilicon deposited and implanted wafers were used to measure the carrier mobility (μ) and the effective carrier concentration (n) with a Hall measurement set-up. For hydrogenation study, after ρ_c , μ , and n were measured, wafers were performed by a hydrogen implantation through the metal at 100Kev with a dose of 2×10^{15} cm⁻², and they were sintered at 300°C, 350°C, 400°C, and 450°C, in N₂ for 60, 120, 180, 240, and 300 min. respectively. Measurements on ρ_c , μ , and n were performed again.

3.RESULTS AND DISCUSSIONS

Fig.2 shows the semi-log plots of the measured specific contact resistivities of the Al(1%Si) /polysilicon and the Al(1%Si)/TiSi₂ /polysilicon contact systems vs. the implanted As⁺ dosage for two different activation or silicidation temperatures. The ρ_{c} values are approximately one order of magnitude higher than those of the Al(1%Si) or the Al(1%Si)/TiSi $_2$ contacts to the single crystalline Si doped with similar As^+ doping levels. However, for the Al(1%Si)/TiSi₂ contact, higher ρ_c values were obtained for 800°C silicidation than for 880°C silicidation, especially for samples of higher implanted As^+ dosages. For the TiSi_2 contact to the single crystalline silicon, $\rho_{\rm C}$ values increase significantly if the silicidation temperature above 800°C. This difference may be due to the fact that for polysilicon, its effective dopant concentration is a function of the final temperature at which the polysilicon is heat-treated. A higher temperature will give more impurity atoms to be inside poly-crystalline grains rather than at grain boundaries, while a subsequent heat-treatment at a lower temperature will move dopant inside grains to diffuse to grain boundaries to give a lower effective dopant concentration. In the figure, the effective doping concentrations of 800°C samples were lower than those of the 880°C samples because their final heat-treatment temperature was lower. This resulted in higher ρ_c .

Fig.3 shows plots of fractions of the activated As⁺ and mobilities of the corresponding samples versus the implanted As⁺ dosage. In the figure, it is seen that for the samples activated at 880°C, less than 0.3 of implanted As⁺ were activated. The mobilities of these samples were 4 to 10 times less than those of the single crystalline Si. These in combination gave higher ρ_c values.

Hydrogenation of polysilicon can improve many electrical characteristics of polysilicon, it is expected that it can also improve the ρ_c values of polysilicon when forming contacts with metals. Fig.4 show the ρ_c values of Al(1%Si)/n⁺-polysilicon contact system before/after the hydrogen passivation in terms of the sintering time for four sintering temperatures. On the figure, the ρ_c values at the t=0 axis are the ρ_c values before hydrogen passivation. Every data point represents for an average value of forty devices. In the figure, it can be seen that ρ_c decreased after hydrogen passivation and ρ_c decreased with the sintering temperature and the sintering time. It can also be seen that increasing the sintering temperature was more effective to improve ρ_c than increasing the







Fig.3 Fractions of the activated As^+ and the mobilities of the corresponding samples.

sintering time, about one order of magnitude decrease in $\rho_{\rm C}$ was achieved for the 450°C sintering and a value of 2×10⁻⁷Ω-cm² was obtained. For this value, it is even comparable to the $\rho_{\rm C}$ value of the

Al(1%Si) to single crystalline Si contact system.⁷) Fig.5 show the plot for the Al(1%Si)/TiSi₂/

polysilicon contact system before and after hydrogen passivation. Compared with Fig.4, the same tendency are observed for this plot. The difference of ρ_c values between the Al(1%Si)/n⁺-polysilicon and the Al(1%Si)/TiSi₂/n⁺ polysilicon contact systems can be described as two folds: (1) before hydrogen passivation, ρ_c values of the Al(1%Si) contact system were higher than those of obtained by the TiSi₂ contact system for the same As⁺ dopant concentration due to the direct reaction of Ti to form a more intimate contact with polysilicon and (2) after hydrogen passivation, ρ_c values of both Al(1%Si) and TiSi₂ contact systems decreased with the sintering temperature and time but the improvement of ρ_c for the TiSi₂ contact system was not as prominent as that of the Al(1%Si) contact system.

Fig.'s 6(a) and (b) show the effective carrier concentration and the effective carrier mobility before and after hydrogen passivation for polysilicon It is seen that the effective carrier films. concentration decreased but the mobility increased after the hydrogen passivation. The effective carrier concentration, decreased after passivation, kept nearly constant with respect to the sintering temperature. The mobility, increased after passivation, decreased as the sintering temperature was above 450°C. The decrease of effective carrier concentrations was caused by the neutralization of n-type impurities in polysilicon by hydrogenation and the increase of mobilities was caused by the passivation of hydrogen atoms on defects at grain boundaries and interfaces. Two main factors affect the contact resistance, namely, the effective carrier concentration of the contacted substrate, and the barrier height which is determined by the surface condition. In combining the data in Fig.'s 4, 5, and 6, for the Al(1%si)/polysilicon or the Al(1%Si) /TiSi₂/polysilicon contacts, the improvement of ρ_{c} after the hydrogen passivation was not caused by the change of the effective carrier concentration but by barrier heights modification through the the hydrogen passivation of interface states.



Fig.4 Hydrogenation effect on $\rho_{\rm C}$ of Al(1%Si)/polysilicon contact system.



Fig.5 Hydrogenation effect on $\rho_{\rm C}$ of Al(1%Si)/TiSi_2/ polysilicon contact system.



Fig.6 Hall measurements of (a) the effective carrier concentrations, n, and (b) the mobilities, u, before and after the hydrogenation.

4.CONCLUSIONS

From the results of Fig.'s 2–6, it can be concluded that ρ_c of Al(1%Si)/polysilicon and Al(1%Si)/TiSi₂/polysilicon contact systems are higher than the same metal and metal silicide contact to the similarly doped single crystalline Si. This is due to the smaller activated fraction of impurities and the lower carrier mobility of polysilicon film than the similarly doped single crystalline Si. For both contact systems, it is seen that ρ_c values can be reduced by means of hydrogen passivation and above one order of magnitude improvement of ρ_c can be

achieved when the samples were sintering at 450 °C after hydrogen implantation and a value of $2\times10^{-7}\Omega$ -cm² for Al(1%Si) contact systems was obtained. From the results of Hall measurements, it is seen that, the mechanisms of the improvement on $\rho_{\rm c}$ by the hydrogenation are not caused by the change of effective carrier concentration but may be caused by the increase of mobility which represents the defect states located within grain boundaries and interfaces of polysilicon are reduced by the hydrogen passivation. Besides, after hydrogen passivation, more uniformity properties for all of the contact systems can be achieved than those of the un-hydrogenation samples.

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