Reverse CoSi₂ Thermal Stability and Digitized Sheet Resistance Increase in Sub-90nm Poly-Si Lines

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1. Introduction

An equation quantifying CoSi_2 thermal stability for poly Si lines ranging from 50nm to 2µm is proposed for the first time and predicts the weakest thermal stability occurs at super-nominal line in 90nm technology. Silicide fabrication is becoming more challenging in advanced technology. Previous literatures studied silicide thermal stability via long-time or high-temperature thermal testing [1] and used force-balance model to explain silicide agglomeration [2]; however, a general equation to quantify silicide thermal stability for engineering design has not been proposed before. We propose a simple equation, Q=C×w×t², to quantify thermal stability as a substrate conditions, line width and silicide thickness. The validity of the equation is demonstrated by matching the trend of sheet resistance (Rs) variation in poly Si lines.

2. Experimental

Cobalt silicide process in a 90nm technology flow is used for wafer processing. The sheet resistance of different poly lines is measured by typical I-V method. Transmission electron microscope (TEM) is used for silicide thickness, poly physical line width measurement and agglomeration examination.

3. Results and Discussion

Equation Derivation

A digitized sheet resistance distribution of sub-90nm p+ poly lines with almost the same amount of Rs increase is shown in Fig. 1. To explain this phenomenon we use TEM to investigate the silicide thickness and the actual line width of the p+ poly lines as tabulated in Table I.

When agglomeration occurs, vacancies migrate and accumulate at the interface. Causing two silicide grains to separate and Rs to increase significantly; thus, thermal stability is inversely proportional to the number of vacancies accumulated at the interface (V) over the cross-sectional area of silicide they occupy (A), as shown in Fig. 2. The amount of vacancies that can migrate and accumulate at the interface is proportional to the grain boundary moving speed, which is also inversely proportional to the silicide thickness (t) [3]. The thermal stability equation can thus be written as

$$Q \propto \left(\frac{V}{A}\right)^{-1} \propto \left[\left(\frac{1}{t}\right) / (w \times t)\right]^{-1} = C \times w \times t^2 \qquad (1)$$

where w is the silicide width, C is a constant related to the microstructure of silicide and the substrate. We then plot wt² using values in Table I as shown in Fig. 3. As predicted in Fig. 4 (a), the drawn 0.13μ m line should have the lowest thermal stability due to lowest wt^2 . Fig. 4 (b) plots wt² and Rs standard deviation for various drawn poly widths. It is shown that wt² and Rs standard deviation are inversely related to each other, which match our prediction very well. In Table II and Fig. 5-6, we use the same methodology to investigate n+ poly lines and find the same equation can also be applied. For a specific drawn line width the value of wt² for n+ poly lines are smaller than its p+ poly counterpart, but its Rs standard deviation is actually smaller indicating better thermal stability for n+ poly lines. This phenomenon can only be explained by the constant in eq. (1), which is larger for n+poly. We also found that the constant for monocrystalline Si is larger than poly silicon lines and conclude $C(n+Si) \sim C(p+Si) > C(n+poly) > C(p+poly)$. Digitized Rs Increase

We investigate group1 samples in Fig. 7 (a) have no failure sites, group2 samples have one failure site as shown in Fig. 7 (b) and group3 samples have two failure sites. The digitized increase amount can actually be estimated analytically. A schematic plot to explain the resistance increase is depicted in Fig. 8.

The Rs increase(R) due to silicide agglomeration is equal to Ra+Rb+Ra'. We can assume the two transitional regions to have same length (L) and Ra=Ra', so R=2Ra+Rb. We further divide Ra into silicide resistor R₁, silicide to poly contact resistance Rc, and poly resistor R₂. By assuming R₁+Rc=R₂ or

$$Rs_1 \times \left(\frac{L}{w}\right) + \left(\frac{Rsc}{w \times L}\right) = Rs_2 \times \left(\frac{L}{w}\right)$$
 (2)

where Rsc is the specific contact resistance of silicide to poly interface, Rs_1 is the sheet resistance of silicide and Rs_2 is the sheet resistance of the non-silicided portion of p+ poly. We then plug in the numbers and using this equation to find the resistance increase $R\approx4.2$ ohm/sq matches our results very well. *Applications*

Fig. 9 shows the p+ poly wt² plot again with a line marked as original thermal stability requirement. This line is drawn below the 0.4 μ m line data point; because the 0.4 μ m line has good thermal stability (small Rs variation). To resolve the agglomeration problem there are two solutions. Approach #1 reduced the thermal budgets and wt² remained unchanged but is above the line, so small Rs variation is observed. Approach #2 increases the silicide thickness so wt² is above the original thermal stability requirement line, thus small Rs variation is achieved. The thickness requirement for a given process can thus be estimated by eq. (1).

4. Conclusion

We propose an equation to quantify silicide thermal stability for engineering use. The equation predicts silicide thermal stability as a function of silicide thickness, line width and substrate microstructure. We also report an interesting phenomenon of digitized Rs increase in p+ poly lines. Calculations of the Rs increase and failure analysis are studied in detail. Application of the equation can be used for process optimization.

References

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Fig. 1. Rs distribution for p+ poly drawn width of 0.09 to 2μ m.



Fig. 2. Current path is blocked by vacancies accumulated at the interface. Smaller area will be more susceptible to Rs increase.



Fig. 3. wt² plot of p+ poly against drawn width.



Fig. 4. p+ poly wt² versus (a) t and w, and (b) standard deviation.



Fig. 7. (a) Varying process conditions can worsen agglomeration, and (b) Agglomeration site of group2 sample in (a).



Fig. 8. Schematic plot for a poly line.



Fig. 9. Examples of equation applied for process optimization.