SYMPOSIUM E

Nucleation and Growth Processes in Materials

November 29 – December 1, 1999

Chairs

Alan J. Ardell
Dept of MS&E
Univ of California-Los Angeles
6531-G Boelter Hall
Los Angeles, CA 90095-1595
310-825-7011

Antonios Gonis
Lawrence Livermore National Lab
L-353
Livermore, CA 94550
925-422-7150

Patrice E. Turchi
Lawrence Livermore National Lab
L-353
Livermore, CA 94551
925-422-9925

Symposium Support
Lawrence Livermore National Laboratory

**Proceedings published as Volume 580
of the Materials Research Society
Symposium Proceedings Series.**

* Invited paper

Upon annealing, these films first crystallize into the metastable C49 structure and then transform to the stable C54 structure. Since the C49 phase exhibits a much higher electrical resistivity than the C54 phase, it is important from an engineering point of view to reduce the C49-C54 transformation temperature, which is usually reported to be 600-800°C. In the present study, we prepared $TiSi_2$ thin films by co-sputtering Ti and Si on silica glass and investigated microstructural evolution and electrical resistivity of these films upon annealing at temperatures between 100 and 800°C. We also prepared ternary $TiSi_2$ containing either Mo, Nb or Au within a few atomic percents to see how these ternary elements affect the C49-C54 transformation behavior. For binary $TiSi_2$, the as-deposited amorphous film exhibits electrical resistivity of 250 $\mu\Omega$cm. Crystallization into the C49 phase occurs at 200°C and this metastable C49 phase persists until the annealing temperature is increased to 700°C at which the C49-C54 transformation starts to occur. While the electrical resistivity gradually decreases with the increase in annealing temperature between 200 and 600°C, the C49-C54 transformation is characterized by a drastic decrease in electrical resistivity. While C49 grains are heavily faulted with 90°-rotational twins, C54 grains are relatively defect-free. Characteristic defects in C54 grains are growth twins with habit planes parallel to (001) and their twinning elements are described by K_1=(110), η_1=[$\bar{1}$10], K_2=(010) and η_2=[100]. The additions of ternary elements are found to reduce the C49-C54 transformation temperature by about 50°C for Mo and Nb and by 100°C for Au.

E5.17
SILICON CRYSTAL GROWTH ON A Ni SILICIDE SEEDING LAYER BY DC MAGNETRON SPUTTERING. Elena Guliants, Wayne A. Anderson, SUNY at Buffalo, Dept of Electrical Engineering, Buffalo, NY.

DC Magnetron sputtering has been applied to polycrystalline Si growth and yielded a uniform Si film at a deposition temperature below the glass softening point. The approach involves the deposition of a thin Ni film over SiO_2 prior to Si sputtering. The interaction of the free electrons of Ni with the covalent Si bonds allows the formation of Ni silicide at the Ni-Si interface immediately after the onset Si deposition. The phase composition of the nickel silicide is controlled by the temperature of deposition and the Si-to-Ni concentration ratio. Thus, at low silicon concentrations, metastable Ni_2Si is formed due to its low activation energy of formation. Promptly after that, NiSi forms by consuming more Si provided by the sputter gun. Although NiSi is known to be thermally stable up to 700°C, the deposition temperature of 525-600°C is argued to be high enough for the NiSi transition to the equilibrium $NiSi_2$ due to additional free energy released through the Si crystallization. These Ni silicide precipitates provide the nucleation centers for Si crystal growth. As a result, the polycrystalline silicon film is shown to consist of 0.1-0.5μm grains with preferred (110) orientation without an indication of an amorphous phase. The carrier lifetime of 11μs indicates good electrical properties which makes the film potentially applicable to thin film transistors and solar cells. The Ni prelayer thickness varied in the 5-100nm range is found to appreciably influence the crystal size and preferential crystal orientation. The maximum grain size occurs for a 25nm thick Ni film. Several possible mechanisms responsible for the nickel silicide induced grain growth of silicon alongside with the correlation between the Ni silicide and silicon microstructure are discussed.

E5.18
PROCESS AND MECHANISM OF $CoSi_2$/Si SOLID PHASE EPITAXY BY MULTILAYER REACTION. Bing-Zong Li, Xin-Ping Qu, Guo-Ping Ru, Fudan University, Dept of Electronic Engineering, Shanghai, CHINA; Ning Wang, P. Chu, City University of Hong Kong, Dept of Applied Physics, Hong Kong, CHINA.

The hetro-epitaxy of $CoSi_2$ on Si substrate is of interest from both material research and potential device application. Recent years the solid phase epitaxy of $CoSi_2$/Si hetro-structure has achieved significant progress by a new approach with a Ti-interlayer mediated epitaxial growth. In this work a novel multilayer structure of Co/a-Si/Ti/Si(100) together with the Co/Ti/Si(100) are applied to investigate the process and mechanism of the phase evolution and epitaxial growth of $CoSi_2$. AES, XRD, RBS/Channeling, TEM and sheet resistance measurements are used to characterize the interdiffusion and interreaction process, layer and compound transformation, silicide film growth and their epitaxial quality. The experimental results show that an epitaxial $CoSi_2$(100) layer with prominent channeling effect can be grown by a proper annealing procedure of such a Co/a-Si/Ti/Si(100) multilayer. By adding an amorphous Si layer with certain thickness the epitaxial quality of $CoSi_2$ is significantly improved, and the minimum channeling yield can be lowered to about 5.2%. An amorphous metastable phase layer is formed by a solid state amorphization reaction at the initial stage of the multilayer reaction. This layer acts as a diffusion barrier, which controls the atomic interdiffusion of Co, Si and limits the supply of Co atoms. It has a vital effect on the multilayer reaction kinetics, and therefore, the epitaxial growth of $CoSi_2$ on Si. The kinetics of the $CoSi_2$ growth process from Co/a-Si/Ti/Si and other structures are investigated systematically. The activation energy of interdiffusion process for different multilayer structures is determined and compared. The results show that the epitaxial growth and the film crystalline quality of $CoSi_2$ are related to the activation energy.

E5.19
CONTROLLED PHASE FORMATION BY USING A DIFFUSION BARRIER — THE Fe-Si REACTION. C.C. Theron, A. Falepin, S. Degroote, J. Dekoster, A. Vantomme, G. Langouche, Catholic University Leuven, Dept. of Nuclear and Radiation Physics, Leuven, BELGIUM; H.S. de Waal and R. Pretorius, National Accelerator Centre, Van de Graaff Group, Faure, SOUTH AFRICA.

Normally, in a cleanly prepared thin-film diffusion couple, the sequence in which phases appear as a result of thermal annealing follows a specific pattern. In such a case the terms first phase formation, phase formation sequence and final phase have clear meanings. During reactive deposition epitaxy (RDE) it has been shown that the phases can be formed directly, thereby changing the phase formation sequence found in solid phase growth (SPG). The rate at which atoms arrive at the reaction interface is crucial in determining the phase that is formed and in RDE this control is achieved by matching the substrate temperature with the deposition rate. If these ideas are to be applied to SPG, then one way of controlling the rate at which atoms arrive at the reaction interface, is to let them pass through a diffusion barrier. The flux of atoms through this diffusion barrier is determined by both the composition of the diffusion barrier as well as its thickness. A basic study of the direct formation of $FeSi_2$ through an amorphous diffusion barrier has been undertaken. Rutherford backscattering (RBS), Mössbauer spectroscopy and X-ray diffraction (XRD) measurements of this reaction are presented. Fe-V and Fe-Zr diffusion barriers were co-deposited in UHV conditions onto chemically cleaned Si(100) substrates, followed by a layer of Fe. RBS was used to verify the stoichiometry and determine the thickness of the layers. ^{57}Fe, a Mössbauer isotope, was selectively placed within the samples, since Mössbauer spectroscopy is ideally suited to distinguish between the different stable and metastable Fe-Si phases that may form in these reaction couples. The results are discussed in terms of what is known about the fundamental diffusion processes occurring in the diffusion barrier as well as the role that thermodynamic driving forces play when the supply rate of reactants is limited.

E5.20
ESTIMATION OF THE CRITICAL RADIUS IN THE NUCLEATION PROCESS OF C54 IN C49 TiSi2: ROLE OF THE DIFFERENCE IN DENSITY. Marcella Iannuzzi, Dmitri Migas, Leo Miglio, INFM and Dip. di Scienza dei Materiali, Univ. di Milano-Bicocca, Milano, ITALY; Valeria Meregalli, Max Plank Institute fur Festkorperforschung, Stuttgart, GERMANY; Maria Grazia Grimaldi, Francesco La Via, INFM, CNR-IMETEM and Dip. di Fisica, Univ. di Catania, Catania, ITALY.

Despite the TiSi2 phase transition between the C49 (metastable, kinetically favoured) structure and the C54 (bulk stable, low resistivity) phase has been extensively studied for metallization and local interconnects of Integrated Circuits, the basic properties of the C49 form are still matter of discussion. In particular, the orthorhombic cell sides, i.e. the volume per formula unit, is larger than the one of the C54 phase, but the quantitative estimation seems to exceed any reasonable volume gap between two polymorphic phases. This issue, still non explaned in literature, has a very important consequence on the strain field which could be produced during the nucleation process of the C54 phase and in turn on its critical radius. By XRD analysis and ab initio calculations we make a new estimation of the C49 density and we draw a new prediction of the critical radius which could explain the low kinetics of the transformation in the case of narrow lines.

E5.21
CHARACTERIZATION OF EPITAXIAL GROWTH OF COMPLEX NON-STOICHIOMETRIC SEMICONDUCTING RHENIUM "DISILICIDE" FILMS. A. Misra, M. Verdier, T.E. Mitchell, Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, NM; J.E. Mahan, Colorado State University, Fort Collins, CO.

The Si-deficient, non-stoichiometric "disilicides" of rhenium, $ReSi_{2-x}$, are narrow band gap semiconductors that are potential materials for infrared detectors. Epitaxial films of $ReSi_{2-x}$ on Si offer the potential of developing heterojunction infrared detection devices where the detector element and the signal processing circuitry can be integrated on one Si chip. We have characterized, through transmission electron

Process and mechanism of $CoSi_2$/Si solid phase epitaxy by multilayer reaction

Bing-Zong Li*, Xin-Ping Qu*, Guo-Ping Ru*, Ning Wang ** and Paul Chu**
*Dept. of Electronic Engineering, Fudan University, Shanghai, 200433, CHINA, bzli@fudan.ac.cn
**Dept. Of Applied Physics, City University of Hong Kong, Hong Kong , CHINA

ABSTRACT

A multilayer structure of Co/a-Si/Ti/Si(100) together with the Co/Ti/Si(100) are applied to investigate the process and mechanism of the $CoSi_2$ epitaxial growth on Si(100) substrate. The experimental results show that by adding an amorphous Si layer with certain thickness the epitaxial quality of $CoSi_2$ is significantly improved. A multi-element amorphous layer is formed by a solid state amorphization reaction at the initial stage of the multilayer reaction. This layer acts as a diffusion barrier, which controls the atomic interdiffusion of Co, Si and limits the supply of Co atoms. It has a vital effect on the multilayer reaction kinetics, and the epitaxial growth of $CoSi_2$ on Si. The kinetics of the $CoSi_2$ growth process from multilayer reactions is investigated.

INTRODUCTION

Epitaxial growth is one of the major crystalline material technique for various solid state electronics and optoelectronic device. Vapor phase epitaxy(VPE) and liquid phase epitaxy (LPE) have been successfully used for growing various homo- or hetro- epitaxial semiconductor structures. In comparison to VPE/LPE and the semiconductor/semiconductor epitaxial structure, the solid phase epitaxy(SPE) and the conductor/semiconductors epitaxial structure are less investigated. The technology knowledge base for SPE is much limited than for VPE/LPE. Metal silicide/Si structure is of great importance for various Si devices [1-2]. The hetro-epitaxy of metal silicide on Si substrate is of interest from both epitaxial material research and its device application [3]. Recent years the solid phase epitaxy of $CoSi_2$/Si hetro-structure has achieved progress by a new approach. By principle the new technology can be called as the interlayer mediated solid phase epitaxy - IMSPE. Two kinds of IMSPE technologies have been under investigation. Ti and some other transition metals(Zr, Ta) have been used as interlayer between Co and Si substrate to mediate the epitaxial growth of $CoSi_2$ [4-11]. Besides such so-called Ti-mediated epitaxy(TIME) [11], it was found that the $CoSi_2$/Si hetro-epitaxy could be realized also by a very thin oxide layer at the Co/Si interface and it was named as a OME technique [12,13].

With the rapid progress of deep submicron ULSI device fabrication technology the $CoSi_2$ is considered as a better alternative material to be used in self-aligned silicide (Salicide) contact and gate level interconnection [14-16]. The epitaxially grown $CoSi_2$ is becoming attractive for the ULSI device fabrication technology [17, 18]. It has been found the epitaxial grown $CoSi_2$ film exhibits higher thermal stability[16, 19].

However, the $CoSi_2$/Si IMSPE technology of both TIME and OME is still not mature enough for its device application. There are various speculations regarding the phase formation, $CoSi_2$ growth kinetics and epitaxy mechanism of the TIME process [4, 5, 20-23]. The exact mechanism of the $CoSi_2$/Si hetro-epitaxial growth by IMSPE has not been fully understood so far. In this work, a multilayer of Co/a-Si/Ti/Si(100) together with Co/Ti/Si(100) are used to

investigated the phase evolution and epitaxially growth of $CoSi_2$ film on Si(100).

EXPERIMENT

Si(100) substrates of both N- and P- type with resistivity of 5-8Ω·cm were used for this study. The thin film deposition of metal (Co, Ti) and amorphous Si was carried out in an Oxford ion-beam sputtering system with a Kaufman ion source. Ar ion beam with energy of 1000eV and current of ~60mA bombarded the metal or Si target in a vacuum chamber with base pressure of 10^{-7} Torr and working Ar pressure of 10^{-5} Torr. Thin layers of Ti, a-Si and Co were deposited sequentially on the well-cleaned Si(100) wafers without breaking the vacuum.

The multilayers of Co/Ti/Si(100) or Co/a-Si/Ti/Si(100) were annealed in a rapid thermal processor (RTP). The rapid thermal annealing (RTA) was performed in the temperature range of 500~1100°C for 10~60 sec in pure N_2 ambient. The composition and compound phase of the samples after RTA were measured by Auger electron spectroscopy(AES) and X-ray diffraction(XRD). The film crystalline structure resulted from the multilayer solid state reaction was characterized by transmission electron microscopy(TEM) and Rutherford backscattering spectroscopy(RBS). Four point probe was applied to measure the thin film sheet resistance and its variation with annealing temperature and time was used to analyze the kinetics of the multilayer solid state reaction.

Results and Discussion

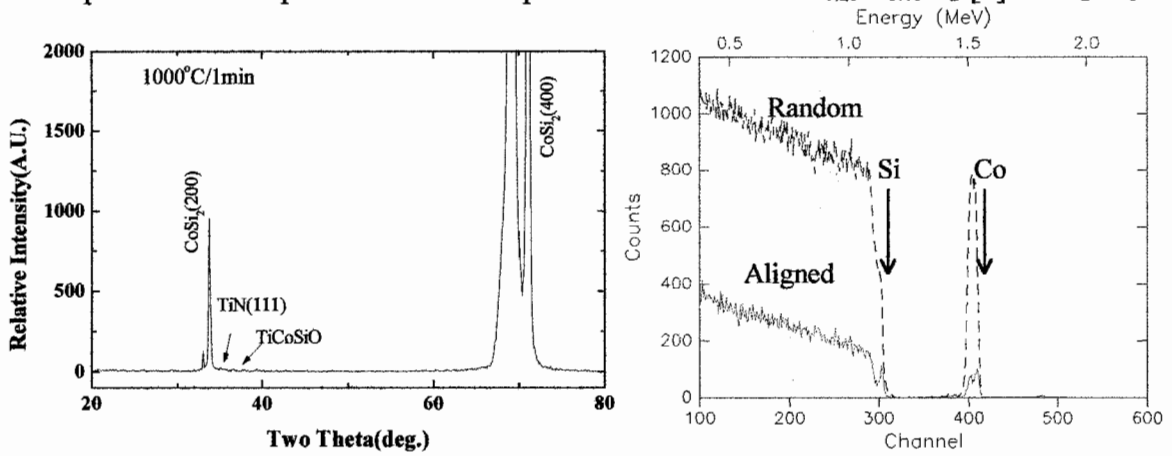
1. The epitaxial growth of $CoSi_2$ by Co/a-Si/Ti/Si(100) solid state reaction

The Co(15nm)/a-Si/Ti(3nm) multilayer structure was deposited on the Si(100) substrate. The thickness of a-Si interlayer was varied from 4nm to 12nm in the experiments. The film characterizations indicate that after high temperature annealing a $CoSi_2$ layer is epitaxially grown on the Si(100) substrate with the same orientation. Fig.1 shows the XRD spectrum of Co(15nm)/a-Si(4nm)/Ti(3nm)/Si(100) after rapid thermal annealing at 1000°C for 1 minute. There are only diffraction peaks of $CoSi_2$(100) series and weak TiN and CoSiTiO peaks. Fig.2 shows the random and channeling Rutherford backscattering spectra of a Co(15nm)/a-Si(4nm) /Ti(3nm)/ Si(100) sample after two step annealing. The film was first annealed at 950°C for 1 minute, then after cleaning by $NH_4OH+H_2O_2$ and diluted HF solutions, it was re-annealed at 1100°C for 10 seconds. Fig.2 shows that the $CoSi_2$ film has abrupt interface with Si substrate. The minimum channeling yield of Co is 5.2%. From these results, it can be seen that adding amorphous Si interlayer can improve the epitaxial quality of $CoSi_2$.

2. Phase evolution during Co/a-Si/Ti/Si(100) solid state reaction

The phase evolution during Co/a-Si/Ti/ Si(100) solid state reaction was investigated by XRD and TEM. Fig.3(a) and 3(b) give the XRD spectra of a Co(15nm)/a-Si(4nm)/Ti(3nm)/Si(100) sample after annealing at 700°C and 750°C for 1 minute. Fig.3(a) shows that after RTA at 700°C for 1 minute, strong $CoSi_2$(200) and (400) diffraction peaks have appeared, which indicates that the epitaxial $CoSi_2$ layer has been formed. Besides these peaks, there are also the CoSi(210), (211) and $CoSi_2$(111), (220) peaks. After RTA at 750°C for 1 minute, the $CoSi_2$(400) peak intensity increases significantly. Some CoSi still remains in the film, but its diffraction intensity becomes very weak. In some work, it is observed that there is a stage at which a ternary silicide layer may be grown as the intermediate phase [8, 22-24].

Various compounds were reported in different publications such as $Co_{0.25}Ti_{0.75}Si_2$ [8] or Ti_2Co_3Si



[22]

Fig. 1 The XRD spectrum of Co(15nm)/a-Si(4nm)/Ti(3nm)/Si(100) after annealing at 1000°C for 1 minute.

Fig. 2 The RBS spectra of Co(15nm)/a-Si(4nm)/Ti(3nm)/Si(100) after two step annealing. The highest temperature is 1100°C for 10 sec.

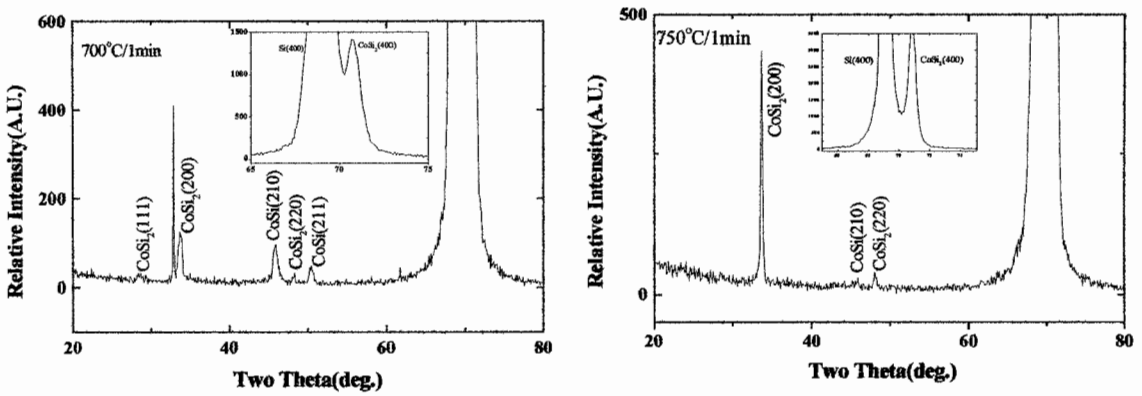


Fig. 3 The XRD spectra of Co(15nm)/a-Si(4nm)/Ti(3nm)/Si(100) after annealing at 700°C(a) and 750°C (b) for 1 minute in N_2 ambient.

or other compounds [23]. Although it is interested to know if there is a kind of barrier layer formed during the annealing process, but from our XRD spectra the corresponding diffraction peak couldn't be observed. We believe that the present result should be related to the following reasons: firstly, in those experiments, thicker Ti layer (>5nm) was applied and caused thicker barrier layer, which favored its appearance in XRD spectra; secondly, in the present experiment, the barrier layer may be amorphous and it is difficult to be observed by XRD especially when the layer is thin.

The TEM results give more information about the phase formation. Fig. 5 is the cross-sectional TEM of Co(15nm)/a-Si(6nm)/Ti(3nm)/Si(100) after annealing at 650°C for 1 minute. From high resolution TEM and selective electron diffraction (SED) analysis, the phase and structure of the film can be analyzed. The TEM micrographs show clearly that after annealing at such a low temperature, a thin epitaxial $CoSi_2$ layer has already been formed at the Si interface. Although the $CoSi_2$ layer is not uniform in thickness, it has good epitaxial orientation with Si substrate. Above the $CoSi_2$ layer, three layers can be seen. A a polycrystalline CoSi layer is next to the epitaxial $CoSi_2$, then an amorphous layer is in between, on its top there is another polycrystalline CoSi layer.

We believe the amorphous layer is formed from multi-element due to solid state

amorphization reaction(SSAR). The adding of an amorphous Si layer may promote the SSAR process. The formed intermediate amorphous layer favors the epitaxial growth of $CoSi_2$. It can act as a barrier layer to reduce the interdiffusion flux of Co and Si. Ogawa et. al [24] also observed the formation of an amorphous layer during Co/Ti/Si reaction. In their study, the amorphous layer was thicker and it still remained after 900°C annealing for 30 minutes. In the present experiment, TEM results show that after 750°C/1min annealing the amorphous layer has become thinner, and after 1000°C/1min annealing, the epitaxial $CoSi_2$ film has a sharp interface with Si and on its top there are TiNO and CoTiSiO polycrystalline layers.

Fig.4 The cross-sectional TEM of Co(15nm)/a-Si(6nm)/Ti(3nm)/Si(100) after annealing at 650°C for 1 minute in N_2 ambient.

3. The kinetics of $CoSi_2$ formation by Co/a-Si/Ti/Si(100) reaction

The kinetics of $CoSi_2$ formation by TIME method is rarely studied. Vantomme et. al. studied the $CoSi_2$ formation of Co(28nm)/Ti(8.5nm)/Si(100) under a vacuum ambient in a narrow temperature range of 675°C to 725°C [8]. The activation energy of $CoSi_2$ formation was found to be 3.5eV. In the present study, the film's sheet resistance is used as a measure of the thickness of $CoSi_2$ layer. Because other compounds formed during reaction have much higher resistivity than $CoSi_2$, the film resistance depends mainly on the thickness of $CoSi_2$. With the approximation that the deposited Co layer is fully converted to CoSi and $CoSi_2$ at the beginning stage of the reaction and the $CoSi_2$ and CoSi layers are considered as two parallel electric resistors [25] , then the films sheet resistance (R_s) has a relation with their resistivity (ρ^{CoSi}, ρ^{CoSi2}) and thickness (d^{Co}, d^{CoSi}, d^{CoSi2}) as: $1/R_s=d^{CoSi}/\rho^{CoSi}+d^{CoSi2}/\rho^{CoSi2}$. It gives a direct relation between $1/R_s$ and d^{CoSi2} as follows:

$$\frac{1}{R_s} = d^{CoSi2}\left(\frac{1}{\rho^{CoSi2}} - \frac{2.02}{3.52}\times\frac{1}{\rho^{CoSi}}\right) + \frac{2.02 d^{Co}}{\rho^{CoSi}} \qquad (1)$$

This formula means that the reciprocal of sheet resistance ($1/R_s$) has linear relation with the $CoSi_2$ film thickness. Fig.5(a) shows the relationship of $1/R_s$ of the Co(15nm)/Ti(3nm)/Si(100) multilayer after iso-thermal annealing with the square root of annealing time. The linear dependence indicates that during the Co/Ti/Si reactions the $CoSi_2$ formation process follows the diffusion-controlled rule. The curves can be fitted by following equation:

$$1 / R_s = k \cdot t^{1/2} + B \qquad (2)$$

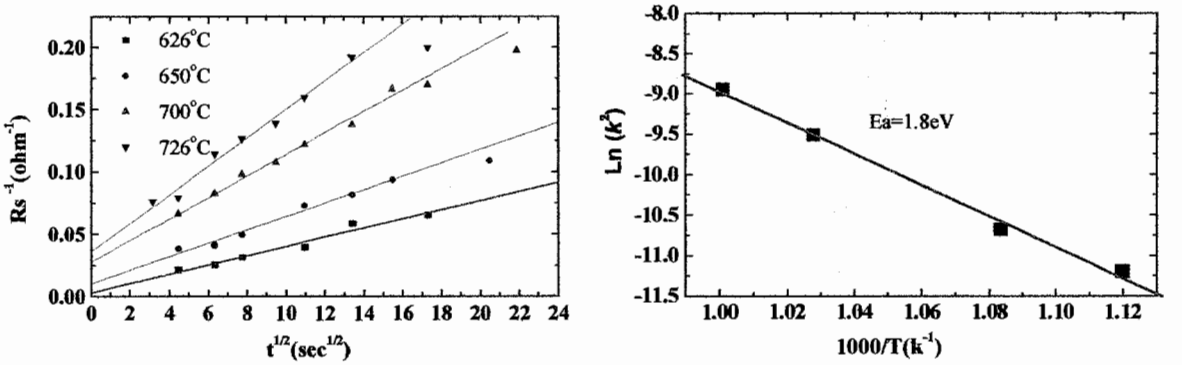


Fig.5 (a) The relationship of the reciprocal of sheet resistance ($1/R_s$) of Co(15nm)/Ti(3nm)/Si(100) after iso-thermal annealing with the square root of annealing time. (b) The Arrhenius plot of the formation of $CoSi_2$.

where, k is proportional to $D^{1/2}$ and D is the effective diffusion coefficient related to the $CoSi_2$ formation.. B is a constant, determined by the resistivity of CoSi and $CoSi_2$. Fig.5(b) is the Arrhenius plot of k^2 with 1/T for the $CoSi_2$ formation. Its slope gives an activation energy of 1.8eV for the $CoSi_2$ formation.

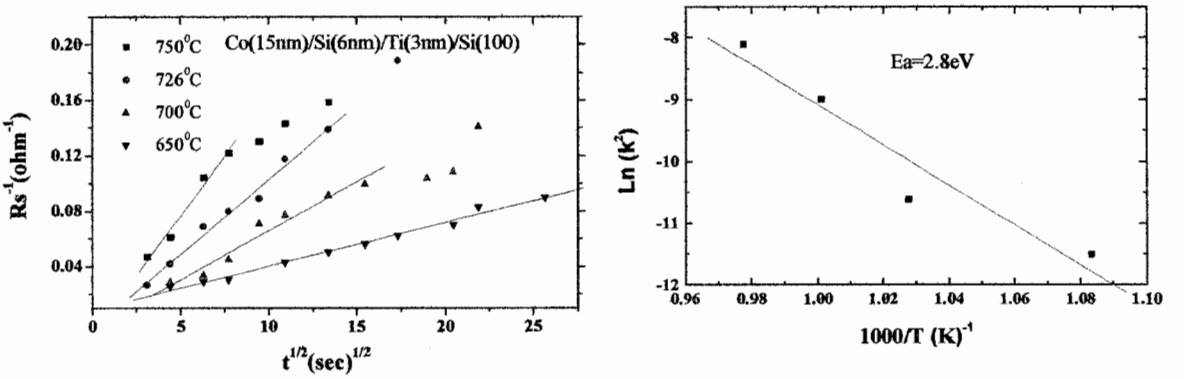


Fig. 6 (a) The relationship of the reciprocal of sheet resistance of Co(15nm)/a-Si(6nm)/Ti(3nm)/Si(100) after iso-thermal annealing with the square root of annealing time. (b) The Arrhenius plot of the $CoSi_2$ formation.

Fig.6 shows the relationship of 1/Rs with $t^{1/2}$ and the Arrhenius plot of the $CoSi_2$ formation by Co(15nm)/a-Si(6nm)/Ti(3nm)/Si(100) reaction. The figures show that the $CoSi_2$ formation from a multilayer with a-Si layer also follows the diffusion-controlled rule. The activation energy is 2.8eV. With an amorphous Si interlayer the activation energy increases. This indicates that the diffusion atoms have to pass a higher barrier to arrive at the growth interface. The TEM microsgraphs indicate that a SSAR process occurred in the initial stage of reaction, the formed amorphous layer may act as a diffusion barrier layer to further slow the reaction between Co and Si. The activation energy data also prove the role of barrier layer.

CONCLUSIONS

A multilayer structure of Co/a-Si/Ti/Si(100) together with the Co/Ti/Si(100) are applied to investigate the process and mechanism of $CoSi_2$ epitaxial growth on Si(100). The strong

characteristic $CoSi_2$(100) peaks and low RBS/channeling yield show that by adding an amorphous Si interlayer the epitaxial quality of $CoSi_2$ is significantly improved. XRD and TEM results show that an amorphous layer is formed by a SSAR process at the initial stage of the multilayer reaction. This layer can act as a diffusion barrier layer, which reduce the atomic interdiffusion of Co, Si. The $CoSi_2$ can be formed directly at the Si interface and grows with the annealing process. The kinetics of formation of $CoSi_2$ by Co/Ti/Si and Co/Si/Ti/Si reaction was studied. The activation energy of $CoSi_2$ formed by Co/Ti/Si is 1.8eV while that formed by Co/Si/Ti/Si is 2.8eV.

ACKNOWLEDEGMENS

This work is supported by Natural Science Foundation of China(NSFC-69776005).

REFERENCES

1. S.P. Murarka, *Silicides for VLSI Applications,* Academic, New York, 1983.
2. *Properties of Metal Silicides*, edited by K. Maex and M. V. Rossum, INSPEC, London, 1995.
3. L.J. Chen, K.N. Tu, Material Science Report, 6, 153 (1991).
4. M.L.A. Dass, D.B. Fraser, and C.S. Wei, Appl. Phys. Lett. 58, 1308 (1991).
5. S.L. Hsia, T.Y. Tan, P. Smith and G.E. McGuire, J. Appl. Phys. 70, 7579 (1991).
6. B.Z. Li, P. Liu, Z. Sun, Z.G. Gu, W.N. Huang, G.B. Jiang, F.Hong, G.A. Rozgonyi, Proc. of 9th VMIC Conference, p. 304 (1992).
7. P. Liu, B.Z. Li, Z. Sun, W.N. Huang, Z.Y. Zhou, R.S. Ni, C.L. Lin, S.C. Zou, F. Hong, and G.A. Rozgonyi, J. Appl. Phys. 74, 1700 (1993).
8. A. Vantomme and Marc-A Nicolet, G. Bai and D.B. Fraser, Appl. Phys. Lett. 62, 243 (1993).
9. B.Z. Li, W.J. Wu, K. Shao, Z.G. Gu, G.B. Jiang, W.N. Huang, H. Fang, Z. Sun, P. Liu, Z.Y. Zhou, Mat. Res. Soc. Symp. Proc. 337, 449 (1994).
10. J. S. Byun, H. J. Kim, J. Appl. Phys. 78 , 6784 (1995).
11. R.T. Tung and F. Schrey, Mat. Res. Soc. Symp. Proc. 402, 173 (1996).
12. R.T. Tung, Appl. Phys. Lett. 68, 3461 (1996).
13. C. Detavernier, R.L. Van Meirhaeghe, F. Cardon, R.A. Donaton , K. Maex, ibid, 20, 2930 (1999).
14. A. Steegen, K. Maex, I. De Wolf, Sym. VLSI Tech. Dig. p. 200 (1998).
15. J.A. Kittl, W.T. Shiau, D. Miles, K.E. Violette, J.C. Hu, Q.Z. Hong, Solid State Technology, 42, 81 (1999).
16. K. Inoue, K. Mikagi, H. Abiko, S. Chikaki, T. Kikkawa, IEEE Transaction on Electron Device, ED-45, 2312 (1998).
17. T. Iinuma, H. Akutsu, K.Ohuchi, K.Miyahshita, Y. Toyoshima, K. Suguro, 1998 Symp. VLSI Tech. Dig. p.188, 1998.
18. K. Shao, B.-Z. Li, S.-X. Zou, W.-N. Huang, W.-J. Wu, H. Fang, W.-F. Yu, G.-B. Jiang, Chinese J. of Semicondutors, 17, 294 (1996).
19. B.Z. Li, Z.G. Gu, G.P. Ru, J. Liu, Proc. of 13th VMIC Conference, p. 187 (1996).
20. B.Z. Li, X.P. Qu, G.P. Ru, H.X. Mo, J. Liu, Proc. of the 5th International Conference on Solid State and IC Technology, p. 251 (1998).
21. J. Cardenas, S. L .Zhang, B. G. Svensson, C. S. Petersson, J. Appl. Phys. 80, 762 (1996).
22. G B. Kim, H. K. Baik, S. M. Lee, Appl. Phys. Lett. 69, 3498 (1996).

23. T. L. Selinder, D. J. Miller, K. E. Gray, Appl. Phys. Lett. 67, 159 (1995).
24. S. Ogawa, J.A Fair, M. L. A. Dass, E. C. Jones, T. Kouzaki, N. W. Cheung, D. B. Fraser, Proc. of 1993 International Conference on Solid State Devices and Materials, p. 195 (1993).
25. A. Appelbaum, R. V. Knoell, S. P. Muraka, J. Appl. Phys. 57, 1880 (1985).