第 21 卷第 6 期 半 导 体 学 报 Vol. 21, No. 6
2000 年 6 月 CHINESE JOURNAL OF SEMICONDUCTORS June, 2000

# Properties of Y-Silicides Synthesized Layer by Y Implantation and RTA Annealing*

ZHANG Tong-he(张通和)[1] and WU Yu-guang(吴瑜光)[2]

(1 *Radiation Beam Technology and Materials Modification Key Laboratory in University, Beijing Normal University,*
2 *Institute of Low Energy Nuclear Physics, Beijing Normal Univesity,*
*Beijing Radiation Center, Beijing* 100875, *China*)

**Abstract**: Synthetic silicides with good properties were prepared, as Y ions were implanted into silicon using metal vapor vacuum arc (MEVVA) ion implantor and annealed by Rapid Thermal Annealing (RTA). The structure of synthetic silicides has been investigated with the analysis of channeled low angle emergence and TEM. Three layers could be observed in the implanted region as the implanting ion flux is selected as $25\mu A/cm^2$. The thickness of the silicide layer is about 60—80nm. The defect density $N_d$ and sheet resistance $R_s$ decrease with the increase of the ion flux. After RTA annealing of the implanted sample, the $N_d$ and $R_s$ decreased obviously. $R_s$ decreased from 54Ω/□ to 14Ω/□. The minimum of resistivity is 84μΩ·cm. It is evident that electrical properties of the Y silicides can be improved by RTA. The formation of the silicides with YSi and $YSi_2$ are confirmed by X-ray diffraction (XRD) analysis. With the analysis of low angle emergence, important information exposed from the depth profiles of atoms and lattice distortion in an implanted region would be used to study the synthesis of silicides.

**Key words**: Y implantation in silicon; low angle emergence channeling; MEVVA ion implantation

**PACC**: 6170T; 6180J

**CLC number**: TN305.3 **Document code**: A **Article ID**: 0253-4177(2000)06-0542-06

# 离子注入硅快速退火合成 Y 硅化物的特性*

* Project Supported by National Natural Science Foundation of China (Grant No. 59671051) and by National High Technology Research and Development (863) Program of China.

ZHANG Tong-he(张通和) was born in 1936. He is a professor adviser for doctor, Vice chairman of Radiation Beam Technology and Material Modification Key Laboratory, Vice chairman of Academic Committee of the Key Laboratory. Research domain: Ion implantation in semiconductors for VLSI technology and Ion Beam modification of materials. E-mail: wuyug@sun.ihep.ac.cn

WU Yu-guang(吴瑜光), femals, was born in 1938. She is a professor, Vice chairman of Beijing Radiation Center, Vice chairman of Institute of Low Energy Nuclear Physics, Beijing Normal University. Research domain: Neutron activation analysis; High-energy ion implantation in semiconductors for VLSI technology; Ion Beam modification of materials.

Received 2 July 1999, revised manuscript received 24 January 2000

张通和[1]　吴瑜光[2]

(1　中国教育部射线束技术和材料改性重点实验室, 2　北京师范大学低能核物理所, 北京辐射中心, 北京　100875)

**摘要**: 用金属蒸发真空弧离子源注入机将 Y 离子注入硅, 制备出特性良好的硅化物。用掠角沟道技术和透射电子显微镜分析了这种硅化物的结构。用束流密度为 25μA/cm$^2$ 的 Y 注入硅可形成三层结构的硅化钇。硅化钇层的厚度大约为 60—80nm. 其缺陷密度 $N_d$ 和薄层电阻 $R_s$ 随束流密度的增加而下降。快速退火后, $N_d$ 和 $R_s$ 都明显下降。$R_s$ 从 54Ω/□下降到 14Ω/□。最小电阻率为 84μΩ·cm. 这说明快速退火可以改善硅化钇的电特性。X 射线衍射分析表明 YSi 和 $YSi_2$ 硅化物已经形成。掠角沟道技术有益于研究薄层硅化物的原子深度分布和晶格缺陷密度分布。

**关键词**: Y 注入硅; 掠角沟道分析; MEVVA 离子注入

**PACC**: 6170T; 6180J

**文章编号**: 0253-4177(2000)06-0542-06

## 1　Introduction

There is a great interest in studying the formation of metallic silicides for the interconnects and ohmic contacts on very large scale integration (VLSI) circuits[1,2]. Synthetic silicide technology of metal ion implantation is a suitable semiconductor process technique of VLSI. When 64-Mbit RAM is fabricated, the depth of a P-N junction is about 0.15μm, so a rather thin ohmic contact layer is required. It is difficult to fabricate extra-thin silicide using conventional technology (PVD, CVD *et al*.) and to control the thickness of silicides. The silicide film is easy to break. However, extra thin silicides with good quality have been fabricated using metal vapor vacuum arc (MEVVA) ion implantation[3,4]. The silicide layer is uniform in thickness and controllable. The electrical properties are perfect. Large beam point of 1 meter in diameter can be obtained using MEVVA ion implantor. To measure the structure of thin silicides, analytical methods with a high depth resolution are needed. The depth resolution of low angle emergence channeling (LAEC) would be satisfactory to this requirement. The structure of the implanted layer has been studied by LAEC for first time in this paper. The details of LAEC technology have been given elsewhere[5,6]. The structure of cross section of the implanted layer was observed using 1000kV TEM. The annealing behavior of implanted samples will be given.

## 2　Experiments and Methods

The MEVVA ion source was operated in a pulsed mode, with a pulse width of 0.3—0.5ms and frequency from 25 to 50s$^{-1}$. Y ions were implanted into P-Si(111) or N-Si(100) at 60keV to dose ranging from $2\times10^{17}$ to $5\times10^{17}$/cm$^2$ with ion flux from 25 to 50μA/cm$^2$. The experimental arrangement of Rutherford Back-Scattering (RBS) and LAEC is given in Fig. 1. Detector 1 is used as a normal RBS at the scattering angle of 168° (see $\theta_1$ in Fig. 1). Detector 2 is used for LAEC analysis at the scattering angle of 97°, so the

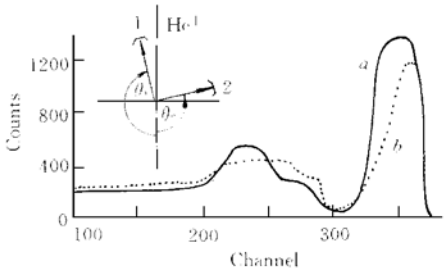


FIG. 1 LAEC Spectra of Y Implanted P-Si(111) (60keV, $4\times10^{17}/cm^2$). Curves: a $25\mu A/cm^2$; b $50\mu A/cm^2$.

detailed structure of the silicide thin layer would be obtained[6]. The anneal of the samples was carried out by irradiation under halogen lamps in temperature ranging from 750 to 1200℃ with various annealing times from 20 to 60s. The cross-section structure of the sample was observed with 1000kV TEM.

## 3 Results and Discussions

### 3.1 LAEC Spectra

LAEC spectra of Y implanted P-Si(111) (60keV, $4\times10^{17}/cm^2$) are given in Fig. 1. Derived from Fig. 1, Y atom concentration profiles are obtained and given in Fig. 2. It is found that the highest concentration of Y atoms appears close to the surface. That is to say that the outdiffusion of Y atom takes place truly. The Y/Si atom ratio is 40% in Y implanted layer when ion flux of $25\mu A/cm^2$ is adopted (see Fig. 2(a)) and metal-rich silicides can be formed under this condition. The Y atom concentration decreases obviously when the ion flux is $50\mu A/cm^2$ as indicates that some Y atoms would be diffused out, instead of accumulating in the implanted region. The Y/Si atom ratio decreases from 32% to 22% (see Fig. 2(b)). Therefore, the silicides are silicon-rich products in this condition. Figure 3 is the depth profile of the lattice distortion derived from Fig. 1. It is interesting to see that a three-layer structure can be observed in the Y implanted silicon with ion flux of $25\mu A/cm^2$. These layers can be distinguished from the difference between their lattice distortion. The first layer is a continual silicide layer with thickness of 60—80nm. The lattice distortion ratio is from 13% to 16%. The second one is a layer with high density of defects, whose thickness is about 120nm, and lattice distortion ratio about 34%. The third one is a lattice distortion layer with low density with thickness being 120nm, and lattice distortion ratio from 5% to 8% (see Fig. 3(a)). The profile was changed greatly when ion flux of $50\mu A/cm^2$ was used. And the lattice distortion ratio in the second layer decreased from 34% to 28%. The shape, corresponding to the first

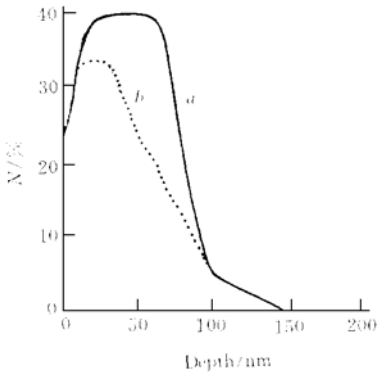


FIG. 2 The Y Atoms Concentration Profiles of Y Ions Implanted into P-Si(111) Using LAEC. Curves: $a$-$25\mu A/cm^2$, $b$-$50\mu A/cm^2$.

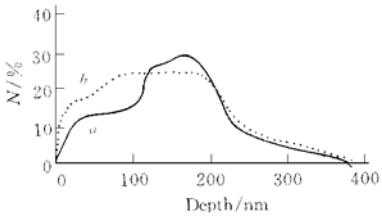


FIG. 3 The Depth Profiles of Lattice Distortion of Y Ions Implanted into P-Si(111) Using LAEC. Curve: $a$-$25\mu A/cm^2$; $b$-$50\mu A/cm^2$.

layer, was changed from a staircase to a platform one. It indicates that the quality of Y silicides implanted with ion flux of $50\mu A/cm^2$ is better than one with ion flux of $25\mu A/cm^2$. The depth profile of the lattice distortion is near a rectangle with a long tail for the case with ion flux of $50\mu A/cm^2$.

### 3.2 TEM Observation

In order to determine the lattice distortion in the implanted layer, the structure of cross-section of the sample was observed under 1000kV TEM (see Fig. 4). It is found from Fig. 4(a) that the first layer is a continual silicide layer with thickness of 60—80nm. The second layer is a damage region of 120nm in thickness with high-density defects. Furthermore, it can be divided into two sub-layers: a lattice damage (defect points) layer and a dislocation layer with high density. The dislocation loops with low density appear in the third layer. If the ion flux of $75\mu A/cm^2$ was used in implantation, the multiple layer structure would disappear, and the silicide layer would be creased, as shown in Fig. 4(b). In order to avoid the crease of silicides, low ion flux and annealing are needed.

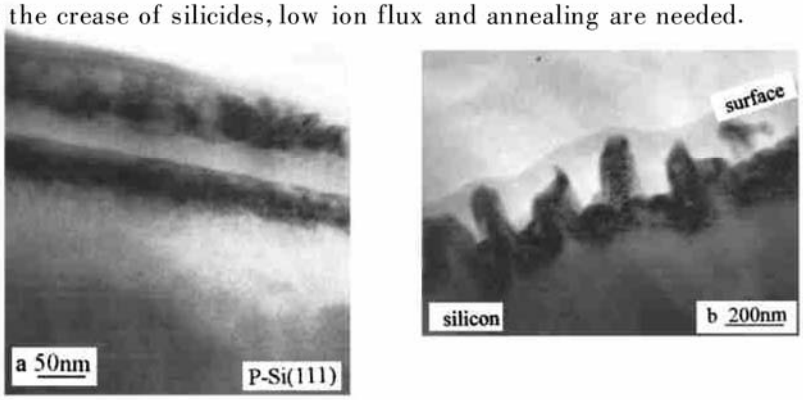


FIG. 4　TEM Photo of Cross-Section in Y Ions Implanted P-Si(111). Ion Flux: a) $25\mu A/cm^2$; b) $75\mu A/cm^2$.

### 3.3 X-Ray Diffraction (XRD) Analysis

Evidence of compounds formed in an implanted layer can be provided with an analysis of XRD. The XRD spectrum of Y implanted (40keV, $3\times10^7/cm^2$, $25\mu A/cm^2$) Si layer is shown in Fig. 5. It is found that silicides of YSi and $YSi_2$ are formed. The preferred growth orientation of YSi and $YSi_2$ are (111) and (101) orientation respectively.

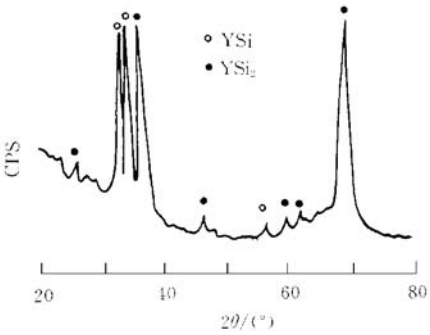


FIG. 5　XRD Spectrum for Y Ions Implanted P-Si(111) with $50\mu A/cm^2$ at 40kV to a Dose of $3\times10^{17}/cm^2$.

### 3.4 Relation Between Sheet Resistance and Ion Flux

The variations in resistance of the implanted layer can provide some information about silicides

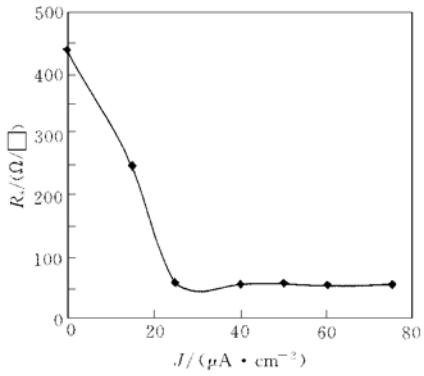


FIG. 6 Relation Between Sheet Resistance $R_s$ and Ion Flux $J$ is Shown in Y Implanted Silicon (92keV, $5\times10^{17}/cm^2$).

formation process. The relation between the sheet resistance $R_s$ and ion flux $J$ is shown in Fig. 6. It is seen that $R_s$ decreases with the increase of ion flux when $J$ is below $25\mu A/cm^2$ and it drops to the minimum 54Ω/□, compared with the sheet resistance of 450Ω/□ for non-implanted silicone. When $J$ is greater than $25\mu A/cm^2$, $R_s$ would keep constant. So nice Y-silicides can be synthesized at ion flux of $25\mu A/cm^2$, but the electrical properties are not improved using higher ion flux.

### 3.5 RTA Annealing

According to above analysis, due to the formation of high-density defects in the silicide layer and high sputtering ratio during Y-implantation at high ion flux, we would not obtain nice Y-silicides without annealing. In order to improve the quality of silicides, the sample should be annealed using RTA from 750℃ to 1200℃ for 20s. When the sample was annealed at 750℃ for 20s, the $R_s$ decreased from 54Ω/□ to 32Ω/□. If the temperature of 1050℃ was selected to anneal, the $R_s$ would decrease to 16Ω/□. After annealing at 1200℃ for 20s, the $R_s$ decreased to the minimum of 15Ω/□(see Fig. 7(a)). When the annealing temperature of 1050℃ retained constant, and the annealing time was changed from 20s to 60s, it was found that $R_s$ decreased from 16Ω/□ to 14Ω/□(see Fig. 7(b)). The minimum of resistivity is about 84μΩ·cm. The optimum of annealing is that the annealing tempearture range is from 1050℃ to 1200℃, and the annealing time from 20s to 60s. It is evident that the electrical properties of the Y silicides can be improved extremely by optimum annealing. With the analysis of low angle emergence, important information exposed from the depth profiles of atoms and lattice distortion in implanted region would be helpful to study the synthesis of silicides.

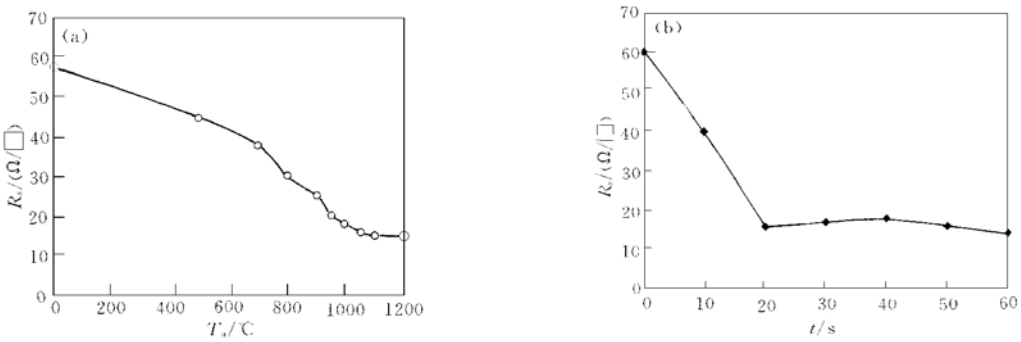


FIG. 7 The relation between sheet resistance $R_s$ and annealing temperature $T_a$ in Y implanted silicon is shown (92keV, $5\times10^{17}/cm^2$). a) Curve of $R_s$-$T_a$, annealing time is 20s; b) Curve of $R_s$-t, annealing temperature is 1050℃

## 4 Summary

Y silicides were formed using MEVVA ion implantation. The depth profiles of lattice distortion and Y atom concentration were single Gaussian distribution using normal channeling and RBS. The structure of Y implanted layer was observed using LAEC and TEM. Main conclusions are as follows:

(1) If $J$ of $25\mu A/cm^2$ was used to Y-implantation, the minimum of $R_s$ could be obtained. It means that the Y-silicides have been synthesized in Y-implanted silicon at this ion flux. The depth profiles of atoms and lattice distortion density show that the Y implanted layer consists of three layers with the different structures and thickness.

(2) If Y implanted at ion flux of $50\mu A/cm^2$, near a rectangular depth profile of lattice distortion is formed with a lower defect density, compared with the case of ion flux of $25\mu A/cm^2$. The qualities of silicides are improved. The outdiffusion of Y atoms is more obvious as Y implanted at ion flux of $50\mu A/cm^2$ than that at ion flux of $25\mu A/cm^2$.

(3) The multiple layer structure of TEM micrograph of cross section is very clear in implanted silicon with ion flux of $50\mu A/cm^2$, if the ion flux of $75\mu A/cm^2$ was used to implantation, the multiple layer structure would disappear, and the silicides be creased.

(4) XRD analysis shows that the silicides of YSi and $YSi_2$ are formed. The preferred growth orientation of YSi and $YSi_2$ are (111) and (101) orientation, respectively.

(5) $R_s$ of Y implanted silicon decreases with the increase of ion flux when $J$ is below $25\mu A/cm^2$ till it drops to the minimum of $54\Omega/\square$.

(6) After RTA annealing of the sample, the $N_d$ and $R_s$ decreased four times. The nice Y silicides can be obtained by RTA annealing. The optimum of annealing is that annealing temperature is from 1050℃ to 1200℃, and annealing time from 20s to 60s.

**Acknowledgements** The authors would like to thank professor G Carter, professor G. A. Stephens and Dr P. Stephens of Salford University in England.

### References

[1] Marc-A. Nicolet and Lan S S, In: VLSI Electronics Microstructure Science, ed. by N. G. Einspruch, Vol. 6, New York, Academic Press, 1983, 329.

[2] Juri Kato and Sejich Iwamatsu, J. Electrochem Soc. Solute State and Technology, 1984, **131**: 1145.

[3] Zhang Tonghe, Chen Jun, Sun Guiru, Wu Yuguang, Wei Fuzhong, Zhang Huixing, Zhang Xiaoji, High Technology Letters, 1993, **4**: 1.

[4] Zhang Tonghe, Chen Jun, Sun Guiru, Wu Yuguang, Luo Yan, Lin Yaijun, Zhang Huixing, Surf. Coat. Technol., 1994, **66**: 355.

[5] Zhang Tonghe and Wu Yuguang, J. of Beijing Normal University (Natural Science), 1994, **27**: 479.

[6] Zhang Tonghe and Wu Yuguang, Nuclear Technology, 1995, **18**: 577.