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Growth of Strained $Si_{1-x}Ge_x$ Layer by UV/ UHV/ CVD*

Hu Huiyong[1], Zhang Heming[1], Dai Xianying[1], Li Kaicheng[2], Wang Wei[1], Zhu Yonggang[1], Wang Shunxiang[1], Cui Xiaoying[1], and Wang Xiyuan[1]

(1 Key Laboratory of Ministry of Education for Wide Bade-Gap Semiconductor Materials and Devices, Microelectronics Institute, Xidian University, Xi'an 710071, China)

(2 National Laboratory of Analog ICs, Chongqing 400060, China)

Abstract: Strained $Si_{1-x}Ge_x$ and Si materials are successfully grown on Si substrate by ultraviolet light chemical vapor deposition under ultrahigh vacuum at a low substrate temperature of 450 ℃ and 480 ℃, respectively. At such low temperature, autodoping effects from the substrate and interdiffusion effects at each interface could be suppressed efficiently. The strained $Si_{1-x}Ge_x$ and multilayer $Si_{1-x}Ge_x$/ Si structures are examined by X-ray diffraction, SMIS, etc., and it is found that the materials have good crystallinity and the rising and falling edges are steep. The technique has a capability of growing high-quality $Si_{1-x}Ge_x$/ Si strained layers.

Key words: $Si_{1-x}Ge_x$; ultrahigh vacuum; ultraviolet light; chemical vapor deposition

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1 Introduction

In recent years, great progress has been made in the study of $Si_{1-x}Ge_x$ materials. The high-quality and practical SiGe materials are obtained mainly by molecular beam epitaxy (MBE)[1] and ultrahigh vacuum chemical vapor deposition (UHVCVD)[2]. In addition, ultraviolet light aided chemical vapor deposition (UVCVD) technique was reported for the growth of $Si_{1-x}Ge_x$ materials[3,4] at low temperature.

To obtain distinct interface of $Si_{1-x}Ge_x$/ Si, which is important to material characteristic, and to prevent contamination of impurity atoms such as carbon, oxygen and so on, the lower growth temperature and the ultrahigh vacuum background are necessary for growing high-quality $Si_{1-x}Ge_x$/ Si materials. The release of the stress in unmatched lattice of $Si_{1-x}Ge_x$/ Si materials is also relative to temperature.

In the paper, strained $Si_{1-x}Ge_x$ materials have been grown using a novel UV/ UHV/ CVD, combining UVCVD with UHVCVD technology. In this technology, the growth of strained $Si_{1-x}Ge_x$ materials is realized by virtue of energy of photon under ultrahigh vacuum at low temperature[5].

2 Systems and principle

Developed by Xidian University, a novel UV/ UHV/ CVD system is used in growing $Si_{1-x}Ge_x$/ Si materials[6]. The schematic of the UV/ UHV/ CVD system is shown in Fig. 1. Considering the requirements for cleanliness of materials growth and the realization of continuous operation, three vacuum

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Hu Huiyong male, was born in 1974. He is engaged in research on novel semiconductor materials, devices, and circuits.

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chambers are employed in the UV/UHV/CVD system, including the preparation chamber, the loading chamber, and the growth chamber. In the preparation chamber, final cleanout of Si substrate are operated under the protection of inert gases. In order to prevent Si substrate from being contaminated during the course of transfer, a loading chamber is used. It is thought that this system can avoid contamination more effectively than other systems with one or two vacuum chambers.

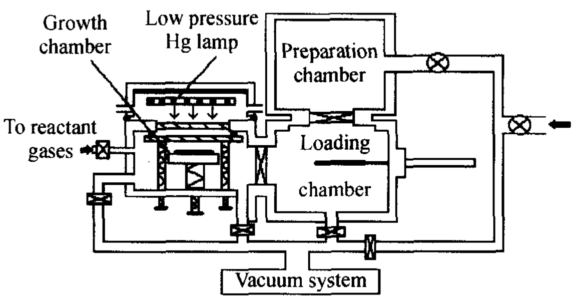

Fig. 1 Schematic of UV/UHV/CVD system

In the study, UV-aided UHV/CVD technology is used. The technology reduces the growth temperature. More importantly, the light source can be turned off between the growth for one layer and the growth for the next layer to improve the interfacial performances of grown multi-structures. Thus it can eliminate the effect of continuous reaction of the residual gases on interfaces during the interval of gas exchange, which happens at a conventional thermal reaction. This is of great benefit to the materials of SiGe HBT and other multilayer devices. During the growth, the reactant gases (including SiH_4, SiH_2Cl_2, GeH_4, B_2H_6, or PH_3) and a small portion of Hg flow into the growth chamber, and ultraviolet light from a low pressure mercury lamp passes into the growth chamber through transparent window, initiating mercury sensitized photodecomposition of the reactant gas to form $Si_{1-x}Ge_x$ or Si film. The influence of Hg on materials quality and characteristic has not been found by far.

As a sensitizer, mercury atoms absorb the energy of UV-light with wavelength of 253.7nm, which is emitted by low-pressure mercury lamp, and are excited from ground state $Hg(^1S_0)$ to excited state $Hg(^3P_1)$. The energy of excited state $Hg(^3P_1)$ is 469.0kJ/mol which is greater than that of ground state. The energy is transferred to molecules of reactant gases by collision to form film precursor radicals, and then the radicals diffuse in the Si substrate surface where they deposit as $Si_{1-x}Ge_x$ or Si[7,8]. Mercury atoms in excited state return to ground state after the collision. The process of reaction is as follows.

(1) $Hg + h\nu \rightarrow Hg'$

(2) $SiH_4 + Hg' \rightarrow SiH_3 + SiH_2 + SiH + Si + H_2 + Hg$

$GeH_4 + Hg' \rightarrow GeH_3 + GeH_2 + GeH + Ge + H_2 + Hg$

$SiH_2Cl_2 + Hg' \rightarrow SiH_2Cl + SiHCl_2 + SiHCl + SiH_2 + SiCl_2 + SiH + SiCl + Si + HCl + Hg$

(3) $Si + Ge \rightarrow SiGe$

3 Experiment and results

The silicon wafers cleaned in atmosphere are put into the preparation chamber, and then finally cleaned. The clean method consists of the organic cleaning and the inorganic cleaning. For example, diluted HF dip is one of the cleaning. With the diluted HF dip, dangling bonds on silicon surface can be passivated by hydrogen. After that, the silicon substrate wafers are transferred to the loading chamber. The growth chamber is always kept in high vacuum. When the vacuum of the loading chamber reaches that of the growth chamber, which is higher than 10^{-5} Pa, the silicon substrate wafers are transferred to growth chamber by magnetic transfer rod. When the vacuum of growth chamber reaches 10^{-8} Pa or higher, the substrate is heated to 750～800 ℃, so that the residual oxide on the surface of silicon wafer can be removed. When the substrate temperature is decreased to the growth temperature, reactant gases are turned on, and the low-pressure mercury lamp is switched on. Then the growth of $Si_{1-x}Ge_x$ or Si materials begins.

The dependences of $Si_{1-x}Ge_x$ quality and the growth rate on substrate temperature have been analyzed and compared. The substrate temperatures used are 300 ,350 ,400 ,450 ,and 480 ℃ respectively. From X-ray diffraction and topology analysis ,it can be seen that the width of $Si_{1-x}Ge_x$ diffraction peak decreases with increased substrate temperature ,but the amplitude of $Si_{1-x}Ge_x$ diffraction peak increases with increased substrate temperature ,and the surface of $Si_{1-x}Ge_x$ materials becomes smoother with the increased substrate temperature.

Analysis results show that $Si_{1-x}Ge_x$ materials grown at 450 ℃ have good crystallinity. The materials characteristics at a temperature higher than 450 ℃ are almost the same as that at 450 ℃. Therefore ,it indicates that high-quality $Si_{1-x}Ge_x$ films can be grown at 450 ℃, but high-quality Si films can be grown at 480 ℃. In Fig. 2(a) ,the X-ray diffraction result of $Si_{1-x}Ge_x$ at the growth temperature of 300 ℃ is shown ,and the diffraction peak of $Si_{1-x}Ge_x$ crystal could not be found. In Fig. 2(b) , the X-ray diffraction result of $Si_{1-x}Ge_x$ at the growth temperature of 450 ℃ is shown. From Fig. 2 (b) ,it can be seen that the X-ray diffraction peak is 34. 36 °, and the full width of half-maximum (FWHM) is 0. 015 °. The quality of $Si_{1-x}Ge_x$ materials is quite good. And the thickness of $Si_{1-x}Ge_x$ layer in Fig. 2(b) is approximately 100nm.

Based on the technology in the paper ,the continuously grown heterostructure ,the sample of n-Si/ i-$Si_{1-x}Ge_x$/ p^+-$Si_{1-x}Ge_x$/ i-$Si_{1-x}Ge_x$/ n-Si , has been obtained, which PH_3 is used as n-type doping source ,and B_2H_6 is used as p-type doping source. Figure 3 is the SIMS (secondary ionized mass spectrum) profile of n-Si/ i-$Si_{0.86}Ge_{0.14}$/ p^+-$Si_{0.86}Ge_{0.14}$/ i-$Si_{0.86}Ge_{0.14}$/ n-Si grown at temperature of 450 and 480 ℃ for $Si_{1-x}Ge_x$ and Si , respectively. It shows that the rising and falling edges are steep ,and the interfaces are distinct.

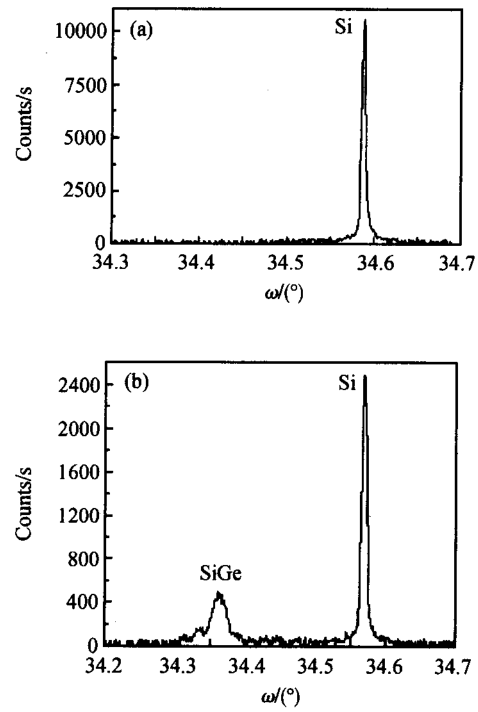

Fig. 2　X-ray diffraction of SiGe grown at 300 ℃ (a) and 450 ℃ (b)

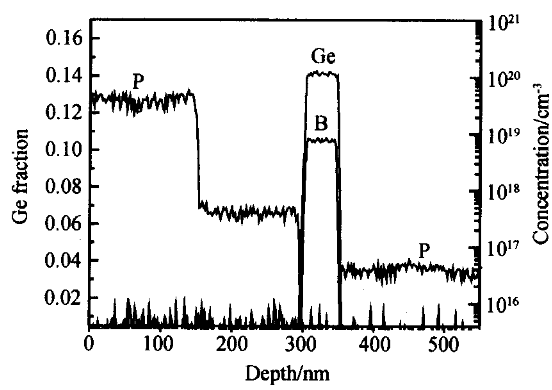

Fig. 3　SIMS profile of n-Si/ i-$Si_{0.86}Ge_{0.14}$/ p^+-$Si_{0.86}Ge_{0.14}$/ i-$Si_{0.86}Ge_{0.14}$/ n-Si

In addition ,the sample is analyzed by the electrochemical *C-V* profiler[9] and the four-probe array[10]. The measured results of P and B doping concentration accord with the results of SMIS.

4 Conclusion

Using UV/ UHV/ CVD technology, the strained $Si_{1-x}Ge_x$/ Si materials have been successfully grown at a low substrate temperature of 450 and 480 ℃ for strained $Si_{1-x}Ge_x$ and Si, respectively. The X-ray diffraction result shows that the crystalline quality is quite good. The SMIS result indicates that rising and falling edges are steep and the interfaces are distinct, which improves the performances of the interface.

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UV/UHV/CVD 生长应变 $Si_{1-x}Ge_x$ 层*

胡辉勇[1] 张鹤鸣[1] 戴显英[1] 李开成[2] 王 伟[1] 朱永刚[1] 王顺祥[1] 崔晓英[1] 王喜媛[1]

(1 西安电子科技大学微电子研究所 宽禁带半导体材料与器件教育部重点实验室, 西安 710071)
(2 国家模拟电路实验室, 重庆 400060)

摘要: 应用紫外光化学气相淀积技术在 450 和 480 ℃超高真空的背景下在 Si 衬底上分别生长出应变 $Si_{1-x}Ge_x$ 和 Si 材料. 在此低温下, 有效地控制了衬底中的杂质外扩以及界面的不清晰. X 射线分析结果表明 $Si_{1-x}Ge_x$ 材料结晶状况良好, 二次离子质谱分析结果表明多层 $Si_{1-x}Ge_x$/Si 材料界面陡峭, 说明该技术能够生长出高质量的应变 Si_{1-x}-Ge_x/Si 材料.

关键词: $Si_{1-x}Ge_x$; 超高真空; 紫外光; 化学气相淀积

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胡辉勇 男, 1974 年出生, 主要从事新型半导体材料、器件与电路研究.

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