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Photochemical Effects for Low-Temperature Si Epitaxy

T.Yamazaki, R.Sugino, T.Ito and H.Ishikawa

FUJITSU LABORATORIES LTD., ATSUGI

10-1 Morinosato-Wakamiya, Atsugi 243-01, Japan

Photochemical low-temperature Si epitaxy in reduced pressure has been developed. Under UV irradiation, single crystal Si which has high crystal quality could be grown at 540°C at 200 Torr. And surface cleaning for Si epitaxy was achieved at 730 °C at 20 Torr using UV irradiation. Auto-doping on As buried layer was negligible, and abrupt profile of boron doping was ahieved using photo-epitaxy.

Introduction

As device size becomes smaller to submicron levels, a low-temperature epitaxial layer with high quality Si crystal is required. Several approaches have been taken to achieve for this, such as MBE[1],LPCVD[2]and plasma enhanced chemical vapor deposition.[3]

Photo-epitaxy using UV irradiation also reduces the growth temperature. A Si photo-epitaxy was investigated in the 1960s.[4][5] More recentry, the authors reported that the Si epitaxial layer could be grown at 630°C at atmospheric pressure using UV irradiation.[6] Photo-epitaxy seems superior to other low-temperature epitaxial techniques because it can be compatible with photo-chemical cleaning of a substrate besides activating source reaction gas for epitaxy.

This paper describes futher reduction of epitaxial growth temperature as well as pre-cleaning temperature by using reduced pressures and high intensity UV irradiation. Improvement of crystal quality and acheivement of doping with a fairly abrupt impurity profile are also described.

Experimental procedure

Our experimental apparatus for photo-epitaxy is shown in Figure 1. The bell jar is made of fuzed quartz. A Si substrate and a SiC coated carbon susceptor were heated from the backside by IR lamp. The pump system consists of a mechanical booster pump and a molecular turbo pump. The reactor ambients were completely oil-free. The base pressure of this system was 8.0×10^{-7} Torr. A high pressure Hg lamp irradiated the Si wafer surface. The intensity is 1 W/cm^2($\lambda <$ 300nm). Disilane source gas which was dissociated under the UV wavelength was used, and diborane and phosphine were used for P-type and N-type doping gases, respectively. A (100) oriented Si wafer cleaned by the conventional wet treatment was used for epitaxy.

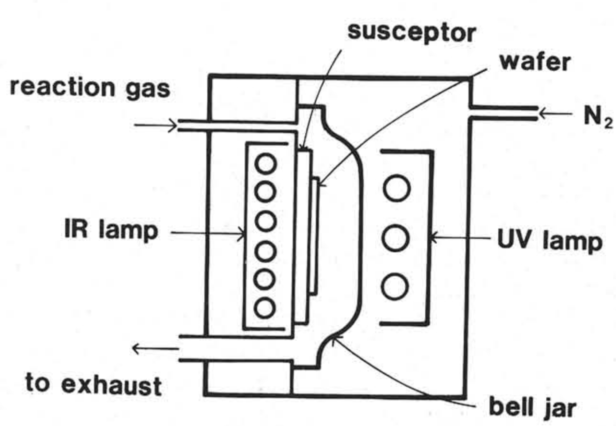

Fig.1 Experimental apparatus

Results and Discussion

1. Epitaxial growth

Si epitaxy was done in the same chamber after the surface cleaning in Si_2H_6/H_2 gas ambient. The temperature dependence of growth rate is shown in Figure 2. Under UV irradiation, the epitaxial growth is possible at a temperature as low as 540°C. From 650°C to 800 °C, the growth rate is inversely proportional to temperature with or without UV irradiation. The growth rate with UV irradiation is about five times that of without UV irradiation. However, below 650°C, under UV irradiation, the growth rate is almost independent on the substrate temperature, and no film is deposited without the UV irradiation. These results indicate that low-temperature Si epitaxy is limited by gas-phase diffusion of photochemically produced radicals, and surface reactions including surface migration of epitaxial species and desorption of by-products, are not rate-determining steps. These may be strongly enhanced by the UV irradiation on the Si substrate.

Figure 3 compares the Raman spectrum of the epitaxial layer grown at 540°C at 200 Torr with UV irradiation and that of a Si substrate. The shape of the spectrum of the epitaxial layer is almost the same as that of the substrate, and FWHM appears nearly the same. Therefore, the photo-epitaxial layer grown at 540 °C has high crystal quality.

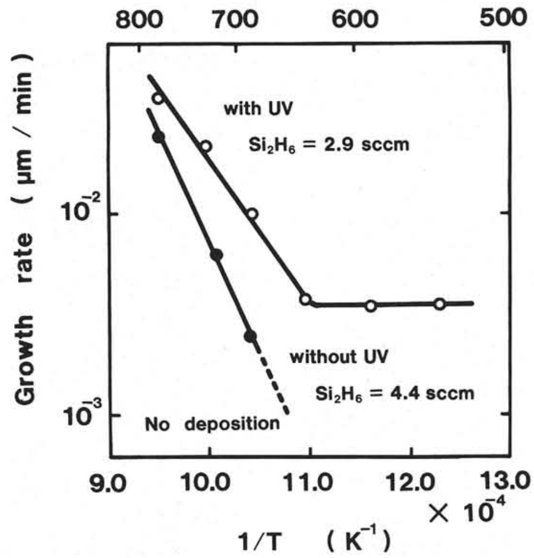

Fig.2 Temperature dependence of growth rate with and without UV irradiation

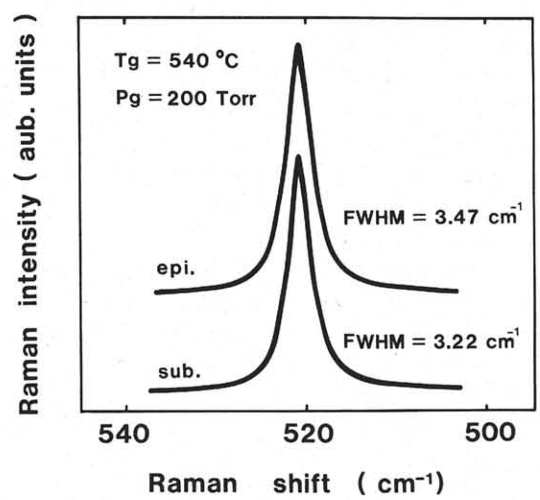

Fig.3 Raman spectra of photo-epitaxial layer and Si substrate

2. Surface cleaning

It is well recognized that native oxide must be removed before epitaxial growth and high temperature heating is conventionally required to remove native oxide and contaminants from the substrate before Si epitaxy. Figure 4 shows the Raman spectra of Si epitaxial layer with 810°C preheating without UV irradiation and with 730 °C preheating with UV irradiation at 20 Torr. These spectra indicate the polycrystalline form and single crystal, respectively. This indicates that the UV irradiation is effective for surface cleaning.

Figure 5 shows the pressure dependence of threshold temperature of surface cleaning. The threshold temperature are about 900°C without UV irradiation. With UV irradiation, the threshold temperatures can be reduced to 820°C at 200 Torr and 730°C at 20 Torr. These results indicate that intense UV irradiation causes photo reduction of native oxide and removal of other contaminants from the Si surface.

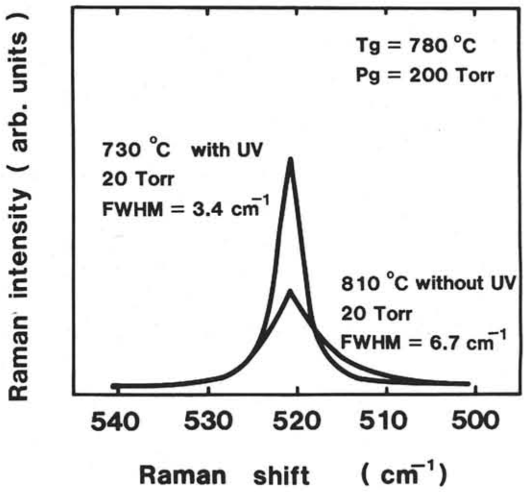

Fig.4 Raman spectra of epitaxial layer with 810 °C preheating without UV and with 730° C preheating with UV

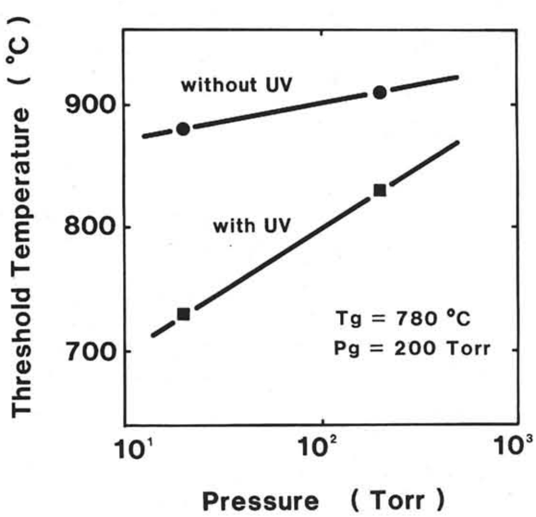

Fig.5 Pressure dependence of threshold temperature of surface cleaning

3. Auto-doping and impurity doping

Figure 6 shows an impurity profile of an epitaxial layer grown on an As implanted layer. Two-step epitaxy was used to suppress auto-doping of impurities and to maintain a relatively high growth rate. After thermal surface cleaning at 980 °C , a photo-epitaxial layer 30 nm thick was grown at 640 °C, and continuously a thermal-epitaxial layer of 1 μm was grown at 780 °C. The transition region with carrier concentration from 10^{19} cm^{-3} to $10^{17} cm^{-3}$ is 280 A. The abrupt impurity profile of epi-sub interface is achieved by low-temperature photo-epitaxial growth.

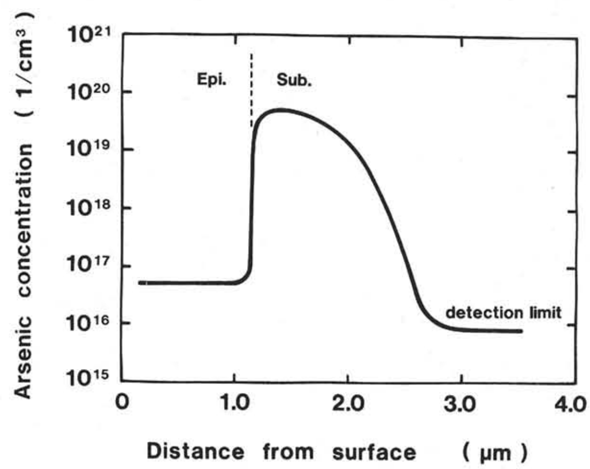

Fig.6 Arsenic profile of the epitaxial layer grown using two-step growth

Figure 7 shows a boron profile of a P-type photo-epitaxial layer on an N-type thermal-epitaxial layer. A boron doped P-type epitaxial layer was grown at 640 °C using photo-epitaxy. The transition distance of boron doping is less than 500 A and an abrupt P-N junction was fabricated.

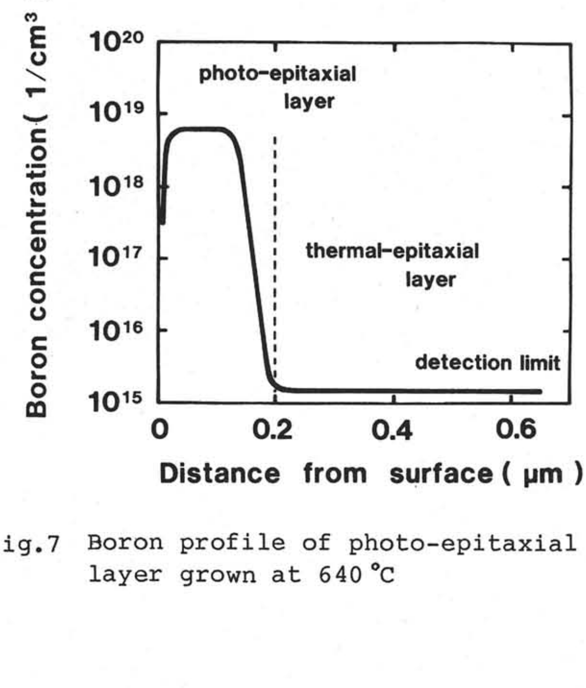

Fig.7 Boron profile of photo-epitaxial layer grown at 640 °C

4. Defects and Electrical properties

Crystal defects such as stacking faults and dislocation were investigated using Secco etching. In low-temperature photo-epitaxial layers, these defects were not observed. However, surface defects such as pits and hillocks were sometimes observed. It seems that these defects were caused by oxide and contamination on the Si surface and impurities in reaction gases.

Figure 8 shows the breakdown voltage between emitter and collector of a bipolar transistor that was made on a photo-epitaxial layer. N-type collector layer and P-type base layer as shown in Figure 7 were grown using photo-epitaxy. The emitter was made by arsenic ion implantation. If there were any crystal defects in the intrinsic base region, the implanted arsenic is diffused irregularly along the crystal defects, and the emitter and collector are shorted. As shown in Fig.8, the E-C breakdown voltage was about 12 V. This result indicates that the crystal defects that cause the E-C short did not exist in the low-temperature photo-epitaxial layer. This feature is attractive for fabricating high-speed bipolar devices with very thin epitaxial layers.

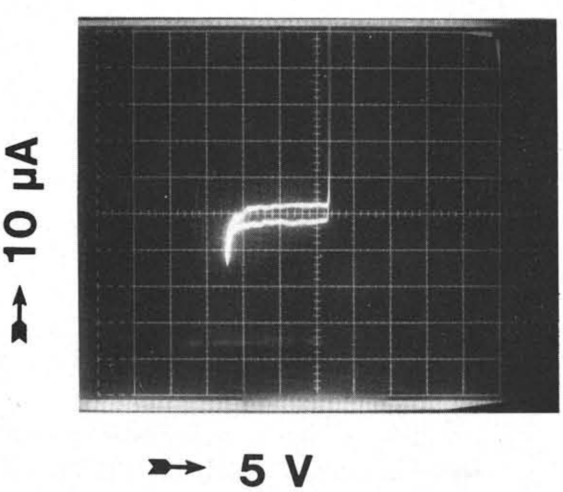

Fig.8 I-V characteristic of E-C of bipolar transistor made on photo-epitaxial layer

Summary

Photochemical low-temperature Si epitaxy at reduced pressure has been developed. Under UV irradiation, surface cleaning for Si epitaxy was achieved at 730 °C at 20 Torr. High quality single crystal Si could be grown at 540°C at 200 Torr. Under UV irradiation, below 650°C the growth rate was independent on growth temperature, and no film was deposited without UV. Auto-doping on arsenic buried layer was negligible, and abrupt profile of boron doping was achieved using low-temperature photo-epitaxy. The crystal defects that cause E-C shorts in bipolar devices did not exist in photo-epitaxial layer.

Acknowledgement

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