

From both the group-III and group-V induced growth study, we find that the V/III incorporation ratio is unity at the transition point.

The study of InGaAs shows that the InGaAs growth rate becomes lower than that of GaAs after several monolayers of InGaAs are deposited at a unity V/III incorporation ratio determined from the binary compound growth study. The growth rate is even lower for higher substrate temperature or higher TMIn flow rate because the indium surface segregation suppresses the Ga deposition rate.

Friday, June 25, 1993, AM

Session P: Group IV Epitaxy

Room: Engineering I-1104

Session Chairman: Bernard S Meyerson, IBM T.J. Watson Research Center, PO Box 218, Yorktown Heights, NY 10598

Co-Chairman: Peter Schwartz, Dept. of Electrical Engineering, University of Iowa, Iowa City, Iowa 52242-6028

8:20 AM, P1

Atomic Layer Epitaxy of Germanium Using Atomic Hydrogen: SHIGERU IMAI, Shin-ya Yamazaki, Toshio Iizuka, Osamu Sugiura and Masakiyo Matsumura, Tokyo Institute of Technology, 2-12-1, O-okayama, Meguro-ku, Tokyo 152, JAPAN

Atomic Layer Epitaxy of Ge has been successfully demonstrated for the first time using alternative exposure of atomic hydrogen (H) and diethylgermane ($\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$).

The system reported previously for Si ALE¹⁾ has been improved to confine the source molecules. A gas supply system provides a fixed volume of $\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$ instantaneously, and valves above and below a reaction chamber confine $\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$ in the chamber. After evacuation of $\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$, H is created thermally from H_2 by a tungsten filament heated at about 2000°C to recover the clean surface by removing C_2H_5 and ad-groups from the surface. The substrate used was of (100)Ge at 250°C.

First the amount of H_2 exposure was varied up to $4.5 \times 10^6 \text{L}$ (Langmuir) with the fixed amount of $\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$ exposure of $2 \times 10^6 \text{L}$. The growth rate was slightly observed without H_2 exposure and increased with the amount of H_2 exposure. It was saturated at the 0.7A/cycle (about 0.5ML/cycle) with the H_{xxx} exposure over $1.5 \times 10^6 \text{L}$. It suggested that C_2H_5 groups on the surface were completely removed by H, which means the self-limitation was completely canceled. It should be worthy to notice that the amount of H_2 exposure necessary for Ge ALE saturation was 10 times larger than that for Si ALE using SiH_2Cl_2 .

Next, the amount of $\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$ exposure was varied up to $2 \times 10^6 \text{L}$ with the relative amount of $\text{H}_2/\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$ fixed at 0.15. The growth rate was tended to be saturated but increased gradually with the amount of the exposure up to 0.7A/cycle. Since this gradual increase of the growth rate seems to be caused by the random growth, the ALE growth seems saturated at 0.5ML/cycle. Up to now an ideal monolayer growth as reported by thermal desorption method²⁾ for $\text{Ge}(\text{C}_2\text{H}_5)_2\text{H}_2$ exposure more than $1 \times 10^6 \text{L}$ has not been observed in our method. The origin of this discrepancy is not clear yet.

The crystallinity of the grown layer was investigated by RHEED. Streak patterns showed that the deposited layer was grown epitaxially. SEM image had no clear surface morphology.

- 1) S. Imai et al., Thin Solid Films (1993), to be published in March issue.
- 2) Y. Takahashi et al., J. Electrochem. Soc., 136, 1826 (1989).

8:40 AM, P2+

Growth Pressure Effects on Si/Si_{1-x}Ge_x Chemical Vapor Deposition: Z. MATUTINOVIC-KRSTELJ, J. C. Sturm and E. Chason+ Department of Engineering, Princeton University, Princeton, NJ 08544, +Sandia National Laboratories, Albuquerque, NM 87185

Recently, several groups have grown Si/Si_{1-x}Ge_x heterostructures by CVD with dichlorosilane (SiH_2Cl_2) and germane (GeH_4) as Si and Ge

sources at various pressures (several torr to atmospheric pressure). This work represents the first comprehensive study of effects of growth pressure on such layers. The material has been characterized by photoluminescence (PL), surface roughness measured by X-ray reflectivity, the electrical performance of resonant tunneling diodes, and layer uniformity.

The Si_{1-x}Ge_x layers were grown in a Rapid Thermal CVD reactor at 625°C, with SiH_2Cl_2 and H_2 flows the same for all samples. The Ge concentration in the alloy layer (x) increased with the increasing pressure for a fixed GeH_4 flow, e.g. for a flow ratio of $\text{SiH}_2\text{Cl}_2/\text{H}_2 = 0.0087$ and $\text{GeH}_4/\text{H}_2 = 0.00027$, "x" equals 20, 30 and 34% for growth pressures of 6, 60 and 220 torr, respectively. The growth-rate of the Si_{1-x}Ge_x layer depended only on "x" in the solid, however, regardless of the growth pressure. The crystal quality of the material, as well as good minority carrier lifetimes were confirmed by PL spectra measured on 250A thick Si_{1-x}Ge_x layers (x = 20 - 34%) at 77K. All the samples clearly showed two thermally broadened peaks corresponding to no-phonon (NP) and phonon-replica lines, as expected for high quality films with low oxygen concentration. The position of the NP peak was used to determine the germanium concentration in the layers. The surface roughness of SiGe layers was determined by measuring X-ray reflectivity using energy dispersive detection. In this technique, the scattering vector is scanned by keeping the scattering angle fixed and measuring the reflected intensity as a function of energy. The samples prepared for this measurement had a ~300Å thick Si_{0.8}Ge_{0.2} layer grown on the top of the Si-buffer at pressures of 6, 60 and 220 torr. The interface roughness ranged from 3.5 (±0.5) down to 2.1A, with a slight trend towards smoother surfaces at higher growth pressures. Another measure of the interface abruptness quality is the performance of resonant-tunneling diodes (RTD's). We have fabricated p-type RTD's with the similar barrier and well widths, grown both at 6 and 60 torr. We have observed similar I-V curves and negative differential resistance for both samples at 90K. No clear difference in the performance of RTD's was observed with respect to the growth pressure, however.

In summary, high quality Si_{1-x}Ge_x layers can be grown from 6 to 220 torr, using SiH_2Cl_2 and GeH_4 . Luminescence and electrical quality is similar at all pressures, but preliminary results indicate that interface abruptness might improve at higher pressure. The work at Princeton was funded by ONR and NSF and that at Sandia National Laboratories by U.S. Dept. of Energy under contract DE-AC04-DP00789.

9:00 AM, P3

"Hybrid" Molecular Beam Epitaxial Growth of Strained Si_{1-x}Ge_x/Si Quantum Wells: YOSKIMINE KATO Tokyo Research Laboratory, IBM Research, 1623-14 Shinto-tsuruma, Yokohama-shi, Kanagawa 242, Japan, Susumu Fukatsu and Yasuhiro Shiraki, Research Center for Advanced Science and Technology (RCAT), The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153, Japan

"Hybrid" epitaxy (HE) of a strained Si_{1-x}Ge_x/Si quantum well (QW) is reported. HE is a growth scheme in which samples are transferred "through the air" between the chambers for gas-source molecular beam epitaxy (GSMBE) and solid-source MBE (SSMBE). In order to demonstrate the power of "hybrid" epitaxy, we present the first successful regrowth of a Si contact layer by SSMBE for electroluminescent (EL) device fabrication on a GSMBE-grown strained Si_{1-x}Ge_x/Si quantum well (QW).

As the first step of HE, a strained Si_{1-x}Ge_x/Si QW (x=0.177) with a well width of 34.2 Å was grown on a p-type 3-inch Si (100) substrate at 740°C by GSMBE using disilane (Si_2H_6) and germane (GeH_4). The sample was subsequently conveyed to the SSMBE chamber through the atmosphere. In spite of considerable air exposure, clear (2x1) reconstruction was routinely obtained after the sample was introduced into vacuum. Extended air exposure up to 15 hours was found to have a negligible influence on the surface reconstruction. The surface was terminated with atomic hydrogen after GSMBE growth, to prevent surface oxidation and facilitate transfer of the sample to the SSMBE chamber without laborious oxide removal.

Following the sample transfer, outgassing was carried out at 450, 650 and 900°C. A well-ordered (2x1) pattern was obtained after thorough degassing. An n-type Si contact epitaxial layer doped with Sb was successfully overgrown at various temperatures between 450 and 650°C.