High Growth Rate of Epitaxial Silicon-Carbon Alloys by High-Order Silane Precursor and Chemical Vapor Deposition

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1. Introduction

The growth of epitaxial strained silicon-carbon alloys are of great interest for use in the source-drain regions of MOSFETs to induce tensile strain in channel regions to enhance electron carrier mobility [1]. In this work, the growth of epitaxial $Si_{1-y}C_y$ alloys by chemical vapor deposition with high substitutional carbon fractions (y~1.8%) and extremely high growth rates at 575°C (~20nm/min) are reported. The high growth rates are enabled by a novel high-order silane (HOS) silicon precursor.

2. Growth of $Si_{1-y}C_y$ Alloys

Achieving high substitutional carbon fraction in $Si_{1-y}C_y$ alloys is important to achieve significant strain for electron mobility improvement. Traditionally, a high substitutional carbon fraction is achieved by a high growth rate and low temperature to incorporate the carbon into substitutional sites in a metastable condition [2][3]. However, achieving a high rate in CVD at low growth temperature is difficult.

We recently have investigated silicon epitaxial CVD at low temperatures using a novel high order silane as a silicon source (Fig 1). For example, without the use of plasmas, at 650°C, the growth rate is 130nm/min and at 575°C it is ~25nm/min. This is at least 2X and 25X faster than epitaxial rates typically achieved by disilane and silane, respectively, at 575°C. The rate at present is limited by our ability to deliver the source into the CVD chamber.

$Si_{1-y}C_y$ alloys were grown by adding methylsilane as a carbon source to the high-order silane (HOS). Experiments were done at 6 Torr in a hydrogen carrier. High-resolution X-ray diffraction (HR-XRD) was done to determine the substitutional concentration of carbon in silicon (Fig. 2 & Fig. 3) and SIMS measurement for total carbon concentration.

The carbon fraction was tuned by increasing the methylsilane flow (until limited by flow controller at 1sccm), and then by decreasing the HOS flow and/or the hydrogen carrier flow. Fig. 4 the shows carbon percentage by X-ray diffraction (XRD) for substitutional carbon and SIMS for the total carbon concentration at 575°C and 6 Torr for different gas flow conditions and varying amounts of hydrogen carrier flows. For the one condition for which both the SIMS and XRD are available (575°C, 6Torr, H_2= 650sccm), both SIMS and XRD indicate a similar carbon fraction 1.05% C vs. 1.1% C incorporated. This indicates that within experimental error the carbon incorporated is 100% substituional.

A comparison of the growth rate versus total carbon concentration [fig 5] indicates that higher growth rates can be obtain for the same epitaxial $Si_{1-y}C_y$ alloys using the novel precursor HOS than disilane in CVD, even at lower temperatures. Our current growth rates of $Si_{1-y}C_y$ alloys with HOS are limited by a low maximum methylsilane flow, which requires reducing HOS flow to increase the fractional carbon percentage. Higher rates are with modified flow controller.

3. Conclusions

High quality $Si_{1-y}C_y$ alloys layers were achieved using a novel high-order silane precursor with methylsilane. Growth rates of $Si_{1-y}C_y$ alloys of 20nm/min a for substitutional carbon of 1.8% and 42nm/min a for substitutional carbon of 1.0% were achieved.

Acknowledgements

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References

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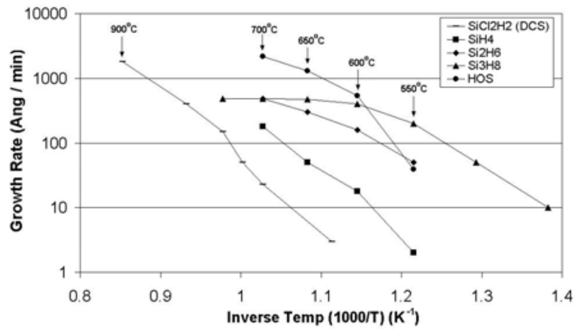

Fig. 1. Comparison of CVD epitaxial growth rates vs. inverse temperature for sources of dichlorosilane (DCS), silane, disilane, trisilane [4], and novel high-order siliane (HOS) precursors on <001> Si substrates

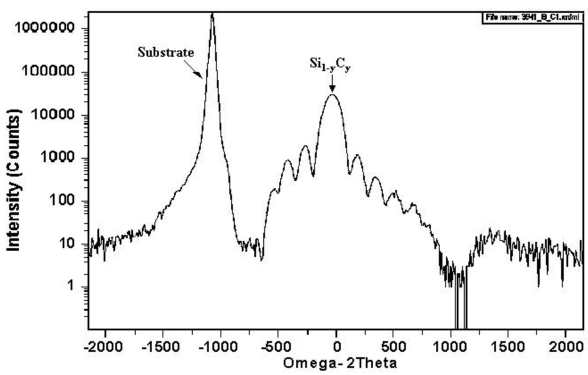

Fig. 2. High-resolution X-ray diffraction (HR-XRD) of sample 3941 (600^{o}C, 6Torr, H_2=1000sccm, $SiCH_6$=1sccm) showing for substitutional carbon level of y=1.2%. Growth rate=14.5nm/min.

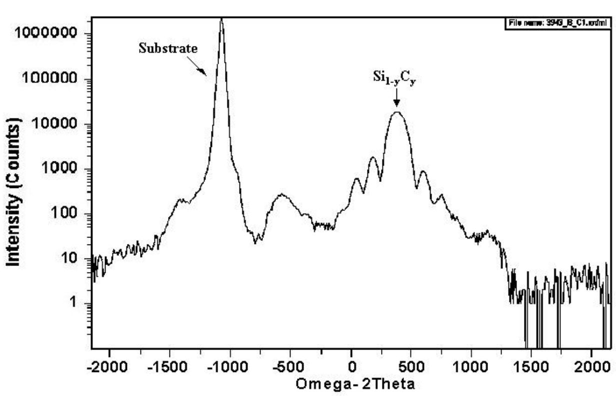

Fig. 3. High-resolution X-ray diffraction (HR-XRD) of sample 3943 (575^{o}C, 6Torr,, H_2=50sccm, $SiCH_6$=1sccm) showing for substitutional carbon level of y=1.6%. Growth rate=20nm/min.

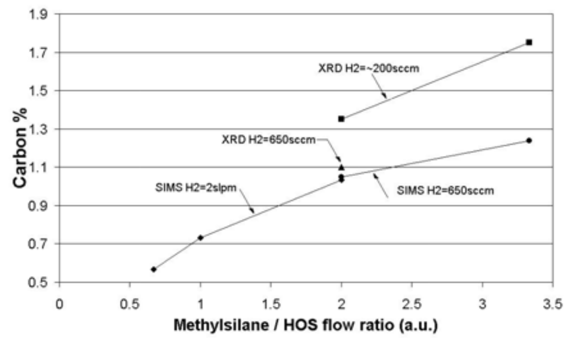

Fig. 4. Carbon fraction (in percent) of $Si_{1-y}C_y$ versus in methylsilane/HOS flow for varying H_2 carrier gas concentrations based on SIMS and x-ray diffraction (XRD). For the one condition with both SIMS and XRD, the carbon fraction are identical within experimental results (1.1% XRD vs 1.05% SIMS), indicating 100% substitutional carbon.

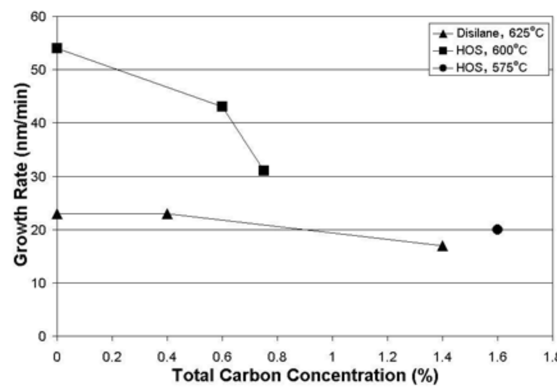

Fig. 5. Growth rate vs. total carbon concentration for varying growth conditions using disilane or HOS in conjuction with methylsilane. The trend of lower growth rates at high carbon concentration for the HOS source is caused by a reduced HOS flow rate and partial pressure required for high C levels due to a limited methylsilane flow.

Due to patent issues, the name of the precursor cannot be disclosed until May 2006.