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This program was comprised of two related efforts dealing with A) the characterization and oxidation of silicon germanium alloy and B) copper-enhanced oxidation. This program supported two graduate students and two undergraduates. The results of this effort are documented in eight publications, a PhD thesis, and an MS thesis.

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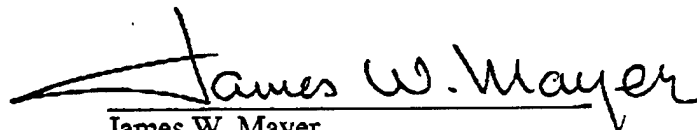
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**FINAL REPORT TO AFOSR****Air Force AASERT Program****Heteroepitaxy of SiGeC on Si**

**James W. Mayer  
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**Abstract**

This successful program supported two graduate students and two undergraduates. The results are documented in 8 publications, the PhD thesis of A. E. Bair and the MS thesis of D. J. Jaquez. All funds were expended.

  
**James W. Mayer  
Regents Professor**

Dec. 8, 1997

8 December, 1997

## ASSERT Program

Air Force  
Heteroepitaxy of SiGeC on Si

## I. Introduction

This program supported 4 ASU Students:

1. A. E. Bair, PhD, now at SGS Thompson
2. J. E. Jaquez, MS, now at Intel
3. Randy Appleton, undergrad, now at Physics, Univ. IL.
4. Justin Shaw, undergrad, graduates ASU, Dec. 97

The undergrads worked in the Ion Beam laboratory in support of the SiGeC program. The publications are listed in Section III. The two theses are:

1. Andrew E. Bair, PhD, May 96  
"Characterization and Oxidation of Silicon, Germanium-Carbon alloys grown by chemical vapor deposition."
2. Edward James Jaquez Jr., Dec. 96  
"Copper Enhanced Oxidation of Si and Group IV Compounds"

## II. Technical results

## A. Characterization and Oxidation of Silicon Germanium Alloy

Pseudomorphic alloys of  $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ , with compositions ranging from  $x \sim 0.20$  and  $0.01 \leq y \leq 0.002$  to  $x \sim 0.50$  and  $0.02 \leq y < 0.04$ ) were grown by chemical vapor deposition. Films with the lower alloy compositions were grown to thickness of 750 nm without the formation of misfit dislocations at the film/substrate interface. This is a four fold increase of the critical thickness over carbon-free alloys with similar Si:Ge ratios. High resolution x-ray diffraction analysis showed all of the pseudomorphic films grown in this study to be in compression. Calculations based on Vegard's law suggested that about 50% of the carbon is compensating for strain induced by the germanium.

The carbon concentrations of the films were quantified using Rutherford backscattering spectrometry (RBS) and elastic recoil detection (ERD). Due to the  $Z^2$  dependence of the scattering cross section, carbon in a heavier matrix cannot be detected with a  $\text{He}^{++}$  ion beam for concentrations in the 0.5 to 10 at.% range. To circumvent this problem, the scattering cross section is enhanced by a factor of about 100 by using the  $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$  elastic resonance at 4.27 MeV.

Target atoms are scattered forward during ERD analysis through a heavy ion filter into a surface barrier signal and a Rutherford cross section can be used. Compositions measured with these techniques of resonance reactions and ERD were in close agreement.

Samples of amorphous  $\text{Si}_{0.67}\text{Ge}_{0.25}\text{C}_{0.08}$  were oxidized in a wet ambient over a temperature range from 700 to 950°C. A discontinuity in the activation energy near 820°C suggested a change in the oxidation mechanism. Below this temperature, a nearly pure  $\text{SiO}_2$  was formed with the germanium being expelled and piling up at the interface. Cross-sectional transmission electron microscopy showed the structure remained amorphous. At temperatures above the transition, the structure became nanocrystalline. The oxide was still nearly pure  $\text{SiO}_2$ , but the expelled germanium redistributed in the remaining alloy layer rather than piling up at the interface.

## B. Copper Enhanced Oxidation

Silicon oxide films ( $> 1\mu\text{m}$ ) were grown at room-temperature after low-energy copper-ion implantation of Si(100) substrates. The structural properties of the silicon oxide layer and the implanted silicon were characterized by Rutherford backscattering spectrometry and transmission-electron microscopy. During room temperature oxidation a portion of the implanted copper resided on the surface and a portion moved with the advancing Si/SiO<sub>x</sub> interface. This study revealed that the oxide growth rate was dependent on the amount of Cu present at the moving interface. The resulting oxide formed was approximately stoichiometric silicon dioxide.

A study of the effects of the additions of C and Ge on the Cu catalyzed oxidation of Si has been performed. It was found that the addition of Ge alone resulted in a marked slowdown in the rate of oxidation. Small amounts of C have a more pronounced effect. Carbon concentrations of less than 2% prevent oxidation for periods of at least one month.

## III. Publications of A. E. Bair & E. J. Jaquez

1. A-39 Z. Atzmon, A.E. Bair, E.J. Jaquez, J.W. Mayer, D. Chandrasekhar, David J. Smith, R.L. Hervig and McD. Robinson, "Chemical vapor deposition of heteroepitaxial Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> films on (100)Si substrates." Appl. Phys. Lett. Vol. 65, pp. 2559-2561 (1994).
2. A-40 Z. Atzmon, A.E. Bair, T.L. Alford, J.W. Mayer, D. Chandrasekhar and David J. Smith, "Wet Oxidation of Amorphous and Crystalline Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> Alloys Grown on (100)Si Substrates." Appl. Phys. Lett. Vol. 66 (17), pp. 2244-2246 (1995).
3. A-45 A.E. Bair, Z. Atzmon, S.W. Russell, T.L. Alford, J.W. Mayer and J.C. Barbour, "Quantification of carbon in Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> with uniform profiles." Nuclear Instruments and Methods in Physics Research B103, 339-346 (1995).
4. A-61 Z. Atzmon, A.E. Bair, S. Sego, David J. Smith, D. Chandrasekhar and J.W. Mayer, "Defect and strain analysis of Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> films grown epitaxially on (100)Si via RBS and TEM." Nuclear Instruments and Methods (accepted).
5. A-72 A.E. Bair, T.L. Alford, Z. Atzmon, S.D. Marcus, D.C. Doller, R. Morton, S.S. Lau and J.W. Mayer, "Cobalt and Titanium Metallization of SiGeC for Shallow Contacts." Materials Research Society Symposium Proceeding. Edited by K.N. Tu, J.W. Mayer, J.M. Poate and L.J. Chen, 427 pp. 529-533 (1996).
6. A-75 B.L. Stein, E.T. Yu, E.T. Croke, A.T. Hunter, T. Laursen, A.E. Bair, J.W. Mayer and C.C. Ahn, "Measurement of band offsets in Si/Si<sub>1-x</sub>Ge<sub>x</sub> and Si/Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> heterojunctions." J. Vac. Sci. Technol., 15 (4) 1108-1111 (Jul/Aug 1997).
7. A-77 E.T. Croke, A.T. Hunter, C.C. Ahn, T. Laursen, D. Chandrasekhar, A.E. Bair, David J. Smith and J.W. Mayer, "Control of composition and crystallinity in the molecular beam epitaxy of strain-compensated Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> alloys on Si." J. of Crystal Growth, 175/176 486-492 (1997).
8. A-78 B.L. Stein, E.T. Yu, E.T. Croke, A.T. Hunter, T. Laursen, A.E. Bair, J.W. Mayer and C.C. Ahn, "Band offsets in Si/Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> heterojunctions measured by admittance spectroscopy." Appl. Phys. Lett. 70 (25) 3413-3415 (23 June 1997).