ECS Transactions, 80 (4) 253-258 (2017)
10.1149/08004.0253ecst ©The Electrochemical Society

Growth and Applications of $Si_{1-x}Sn_x$ Thin Films

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Toward creation of a direct gap group-IV semiconductor, we have developed a new method of growing $Si_{1-x}Sn_x$ layers with various Sn content including a very high Sn content around 40% by using solid phase epitaxy. Crystallographic analyses indicate that grown $Si_{1-x}Sn_x$ layers are nearly lattice-matched to the substrates, specifically, the substitutional Sn contents of ~20 and ~40% are achieved for case of growth on (001)-oriented Ge and InP substrates, respectively. Although band structure of the $Si_{0.6}Sn_{0.4}$ layers grown on InP is still indirect band gap, the difference between the indirect and direct band gap energies decreases from 3.01 (Si) to 0.14 eV ($Si_{0.6}Sn_{0.4}$) following Sn substitution.

Introduction

Integration of near-infrared light source/detector on Si chips has long been expected to achieve on-chip and/or chip-to-chip optical interconnectivity. However, the indirect band gap of group-IV semiconductor such as Si and Ge remains a challenge especially for photoemission. As you know, the strategies to produce Ge-based direct semiconductors involve introducing tensile strain (1,2) and substitutional Sn atoms (3–5) into the Ge lattice, which reduce the energy difference between the indirect and the direct band gap in Ge (0.14 eV). Recent experimental results in $Ge_{1-x}Sn_x$ (5–16) suggest the onset of a direct band gap at a Sn content of 6%–8% for strain-free $Ge_{1-x}Sn_x$. However, the energy bandgap of direct transition $Ge_{1-x}Sn_x$ is sometimes slightly narrow considering near infrared (IR) applications of optical communication for Si ultra large-scale integrated circuits.

$Si_{1-x}Sn_x$ binary alloys have a potential to solve this concern. Although the direct band gap in Si is 3.1 eV above the indirect band gap and the solid solubility limit of Sn in Si is extremely low (0.1% at 1066°C (17)), the $Si_{1-x}Sn_x$ alloys, in principle, must have a direct band gap for a sufficiently high Sn content (18–23), as for $Ge_{1-x}Sn_x$. Some simulation models have been proposed to calculate the $Si_{1-x}Sn_x$ band structure yielding quite a large variation in the predicted Sn content, at which the material transitions from indirect to direct band-gap crossover: specifically, ~25% (19), around 60% (4,20,23), more than 90% (18). Towards creation of a direct transition $Si_{1-x}Sn_x$, some growth techniques such as molecular beam epitaxy (24) and chemical vapor deposition (19) have been reported, where they achieved ultra-thin $Si_{1-x}Sn_x$ layers (e.g., 1-nm-thick $Si_{0.84}Sn_{0.16}$ and 10-nm-