Journal of ELECTRONIC MATERIALS, Vol. 42, No. 1, 2013
DOI: 10.1007/s11664-012-2337-6

Poisson Ratio of Epitaxial Germanium Films Grown on Silicon

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An accurate knowledge of elastic constants of thin films is important in understanding the effect of strain on material properties. We have used residual thermal strain to measure the Poisson ratio of Ge films grown on Si ⟨001⟩ substrates, using the $\sin^2\psi$ method and high-resolution x-ray diffraction. The Poisson ratio of the Ge films was measured to be 0.25, compared with the bulk value of 0.27. Our study indicates that use of Poisson ratio instead of bulk compliance values yields a more accurate description of the state of in-plane strain present in the film.

Key words: Germanium film, Poisson ratio, x-ray diffraction

The presence of residual strain can have a significant effect on material properties of thin films. In the case of epitaxial germanium (Ge) thin films grown on silicon (Si), the presence of residual in-plane tensile strain leads to a decrease in its direct as well as indirect band gap.[1,2] Residual strain in thin films consists of three components: (i) lattice misfit strain, (ii) thermal misfit strain (coefficient of thermal expansion, CTE), and (iii) defect strain.[3] The lattice misfit strain is given by $[1 - (a_{Ge}/a_{Si})]$, where a_{Ge} (0.56 nm) and a_{Si} (0.54 nm) are the lattice parameters of Ge and Si, respectively. This translates to an in-plane misfit strain of −4.2%. The negative sign indicates compressive strain in the Ge film. Since the critical thickness for pseudomorphic epitaxial growth of Ge on Si is ~1 nm,[4] the misfit component is expected to be fully relaxed for films grown at elevated temperatures via the formation of dislocations that nucleate at the free surface and glide to the interface.[5] On the other hand, the thermal component of the residual strain is proportional to $(\Delta\alpha \times \Delta T)$, where $\Delta\alpha$ is the difference in coefficients of thermal expansion of Si and Ge in the temperature interval ΔT. This strain is expected to be on the order of +0.24%, where the positive sign indicates tensile strain in the film. The magnitude of the thermal strain is much smaller and also opposite in sign compared with the misfit strain. The thermal strain is expected to be unrelaxed since the mechanism of relaxation involves the nucleation of dislocations and glide in a relatively thick film. The residual strain in Ge has been experimentally shown to be tensile, and the thermal misfit component was conjectured to be one of two possible causes of this residual strain.[2] Since elastic constants of Ge thin films are not experimentally known, the in-plane strain is normally calculated using bulk elastic compliances of Ge and experimentally measured perpendicular strain using x-ray diffraction. The drawback of this approach is the implicit assumption that the elastic properties of thin films are the same as their bulk counterparts. The main purpose of this paper is to determine the Poisson ratio of Ge thin films using the high-resolution x-ray diffraction (HRXRD)[6] technique. Since the film has an inherent residual thermal strain, the principal idea is to measure the in-plane and parallel strain components in the film to compute the Poisson's ratio. Since the residual thermal strain is small, the measured strain should be related to the elastic response of the film rather than any plastic yield or inelastic phenomenon. A similar concept, which employed the use of a known residual thermal strain to measure yield stress by HRXRD, has been reported earlier for polycrystalline Pb[7] and Al-2%Cu[8] thin films on Si.

Epitaxial Ge films with two-dimensional morphology were grown on ⟨001⟩ Si substrates by the commonly used two-step growth technique.[9] The

(Received August 15, 2012; accepted October 26, 2012; published online November 10, 2012)