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Solid phase epitaxial growth of Dy-germanide films on Ge(0 0 1) substrates

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ABSTRACT

Dy thin films are grown on Ge(0 0 1) substrates by molecular beam deposition at room temperature. Subsequently, the Dy film is annealed at different temperatures for the growth of a Dy-germanide film. Structural, morphological and electrical properties of the Dy-germanide film are investigated by *in situ* reflection high-energy electron diffraction, and *ex situ* X-ray diffraction, atomic force microscopy and resistivity measurements. Reflection high-energy electron diffraction patterns and X-ray diffraction spectra show that the room temperature growth of the Dy film is disordered and there is a transition at a temperature of 300–330 °C from a disordered to an epitaxial growth of a Dy-germanide film by solid phase epitaxy. The high quality Dy_3Ge_5 film crystalline structure is formed and identified as an orthorhombic phase with smooth surface in the annealing temperature range of 330–550 °C. But at a temperature of 600 °C, the smooth surface of the Dy_3Ge_5 film changes to a rough surface with a lot of pits due to the reactions further.

1. Introduction

Germanium as a channel material has attracted much attention due to the higher electron and hole mobilities than silicon [1–4]. Silicides have been used as ohmic contacts, Schottky barrier contacts, gate electrodes, local interconnects and diffusion barriers [5–7]. Metal silicide thin films are an integral part of all microelectronic devices, whereas metal germanide thin films will also be integrated into the next generation nanoelectronics devices [8–10]. The Dy-germanide thin film is a promising candidate for the source/drain contacts. Furthermore, the deeper understanding and knowledge of the Dy-germanide formation is of importance to investigate the structure, crystalline transition, crystalline quality and morphological properties of all thin film germanides. Moreover, there are reports on $DySi_x$ materials grown on Si substrates [11–13], but there is no report at all on the epitaxial Dy-germanide thin film growth on Ge(0 0 1) substrates.

In this paper, the epitaxial Dy-germanide process is proposed for Ge-MOSFETs for the first time. Dy thin films are grown on Ge(0 0 1) substrates by molecular beam deposition (MBD) at temperatures close to room temperature (RT). Subsequently, Dy films are annealed by solid phase epitaxy (SPE) at different high temperatures which leads to the formation of crystalline Dy-germanide films epitaxially grown on Ge(0 0 1) substrates. Structural, morphological and electrical properties of the $DyGe_x$ film are investigated by *in situ* reflection high-energy electron diffraction (RHEED), and *ex situ* X-ray diffraction (XRD), atomic force microscopy (AFM) and resistivity measurements.

2. Experimental procedure

Thin films of $DyGe_x$ are grown on Ge(0 0 1) substrates in a solid-source MBE system (DCA Instruments, Finland). This MBE system is connected to a load lock chamber for a sample transfer and is equipped with a RHEED setup to perform structural investigations during the growth of the film. The base pressures for the load lock and the growth chamber are better than 2×10^{-8} and 2×10^{-10} mbar, respectively. Pure Dy metal (99.7%) is evaporated from a Knudsen cell (K-cell). Ga-doped *p*-type Ge(0 0 1) wafers with a resistivity of 0.011–0.23 Ω cm are used as starting substrates. The Dy growth rate – measured by a quartz crystal microbalance – is 7 Å/min. Ge substrates are cleaned by annealing at high temperature and 50 Å-thick Dy (nominal) thin films are then grown on the reconstructed Ge(0 0 1)-(2 × 1) surface at RT in a pressure of 5×10^{-10} mbar. Subsequently, the Dy thin film is annealed at high temperatures for 20 min in a background pressure of 4×10^{-10} mbar for the formation of crystalline $DyGe_x$ thin films.

The crystallinity of the film surface during the growth is monitored in real time by *in situ* RHEED with an acceleration voltage of 15 keV (Staib Instruments GmbH, Germany). Moreover, the crystallinity of the $DyGe_x$ film is studied by *ex situ* XRD using Cu-Kα

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X-rays (Philips, The Netherlands). The surface morphology of the film is observed by *ex situ* tapping-mode AFM (Digital Instruments, USA). The resistivity of the film is measured by the four-point probe method.

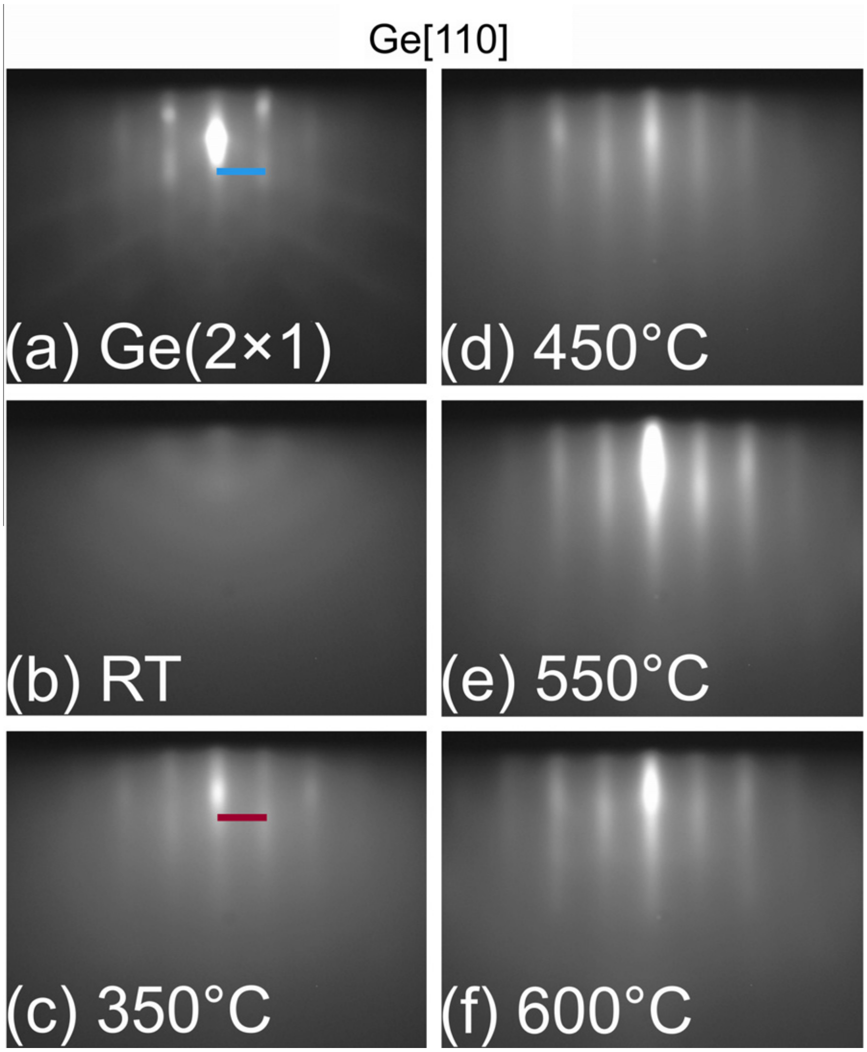

Fig. 1. RHEED patterns of the Dy_3Ge_5 film grown on the reconstructed (a) Ge(0 0 1)-(2 × 1) superstructure at (b) RT and subsequently followed by SPE at high temperatures of (c) 350 °C, (d) 450 °C, (e) 550 °C and (f) 600 °C. RHEED patterns are taken along the incident Ge[1 1 0] azimuth.

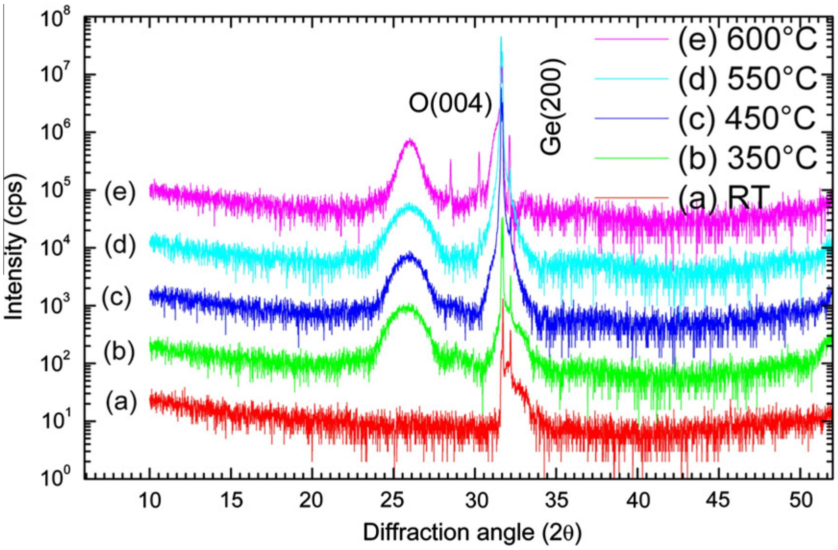

Fig. 2. XRD spectra of the Dy_3Ge_5 film grown on the (a) Ge(0 0 1)-(2 × 1) surface.