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Orientation Relationship and Growth Direction Determination of Gd_5Ge_3 Phase in Gd_5Ge_4 Matrix

O. Ugurlu,* ** L.S. Chumbley,* ** T.A. Lograsso,** and D.L. Schlagel**

* Department of Materials Science and Engineering, Iowa State University, Ames, IA 50011
** Ames Laboratory, Iowa State University, Ames, IA 50011, USA

Gd_5Ge_4 alloy is a member of the $RE_5(Si_xGe_{1-x})_4$ group of alloys, where RE=Rare Earth. These alloys have received significant research interest after the discovery of their giant magnetocaloric effect (MCE), in 1997 [1], which make them possible candidates for next generation magnetic refrigerators. The MCE temperature of $RE_5(Si_xGe_{1-x})_4$ alloys is tunable to temperatures between ~210 and ~276 K by adjusting the Si:Ge ratio [2].

$RE_5(Si_xGe_{1-x})_4$ alloys have three different types of crystal structures depending on the Si:Ge ratio, temperature and magnetic field: Gd_5Si_4-type orthorhombic, $Gd_5Si_2Ge_2$-type monoclinic and Sm_5Ge_4-type orthorhombic. Recent electron microscopy studies have shown that thin-plates of $RE_5(Si_x,Ge_{1-x})_3$ phase grow in virtually every $RE_5(Si_xGe_{1-x})_4$ alloy yet studied, independent from the matrix crystal structure [3, 4] and the specific RE used in the alloy.

In this study Gd_5Ge_4 has been used as the matrix material to identify the orientation relationship and growth direction of Gd_5Ge_3 thin-plates. It has been observed that there are two sets of thin-plates growing parallel to $[010]_m$ with an angle of approximately ~80° between them, Fig 1. Selected Area Diffraction (SAD) patterns from both variants show a clockwise and counter-clockwise rotation of 7° angle between the $(100)_m$ and $(0001)_p$ planes, Fig 2.. This rotation between the planes has also been observed using High-Resolution TEM (HRTEM), Fig 3.

The orientation relationship between the Gd_5Ge_3 thin plates and the Gd_5Ge_4 matrix was determined as $[-1010](1-211)_p//[010](10-2)_m$ using the SAD patterns taken from both phases at different orientations and incorporating this data into stereographic projections.

Growth directions of the two variants were not parallel to any low-index crystallographic orientations, as stated in Ref. [5]. HRTEM studies revealed that the interface has a ledged and terraced structure indicating the presence of invariant line strain, which allows the variants to grow along an invariant line, Fig 3. The growth direction of the variants has been calculated as parallel to $(22\ 0\ 19)_m$ and $(22\ 0\ -19)_m$ using the Δg approach of Zhang and Purdy [6].

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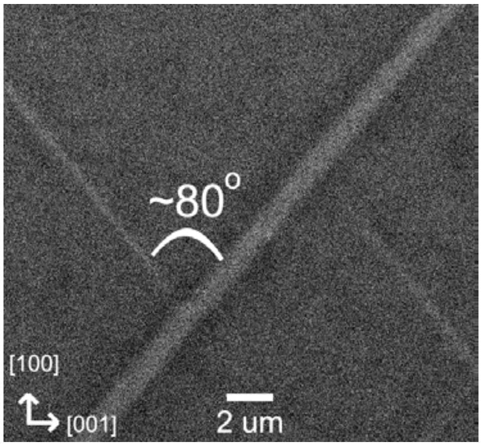

Figure 1. Backscatter SEM image of a single crystal sample. Surface has been oriented perpendicular to [010] direction using back-scattered Laue x-ray diffraction.

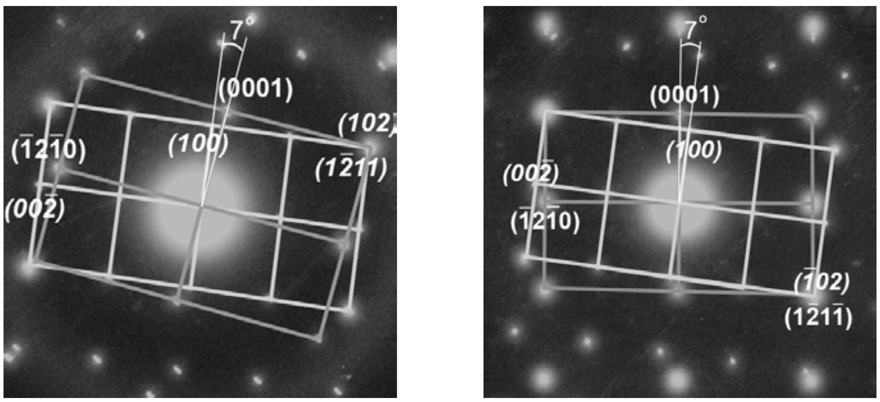

Figure 2. SAD patterns taken from two variants of the thin-plates B=[010]. (a) variant #1 (b) variant #2

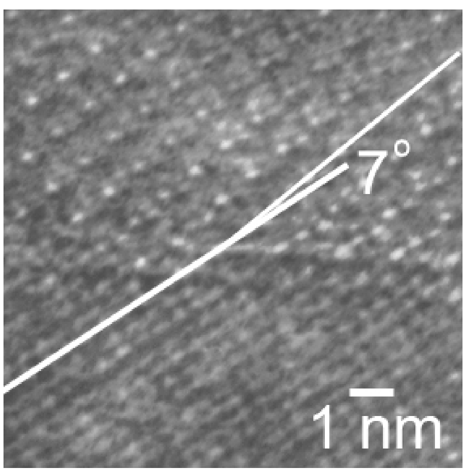

Figure 3. HRTEM image of the interface between Gd_5Ge_3 thin-plate and Gd_5Ge_4 matrix phase. Angle between $(100)_m$ and $(0001)_p$ is 7°.

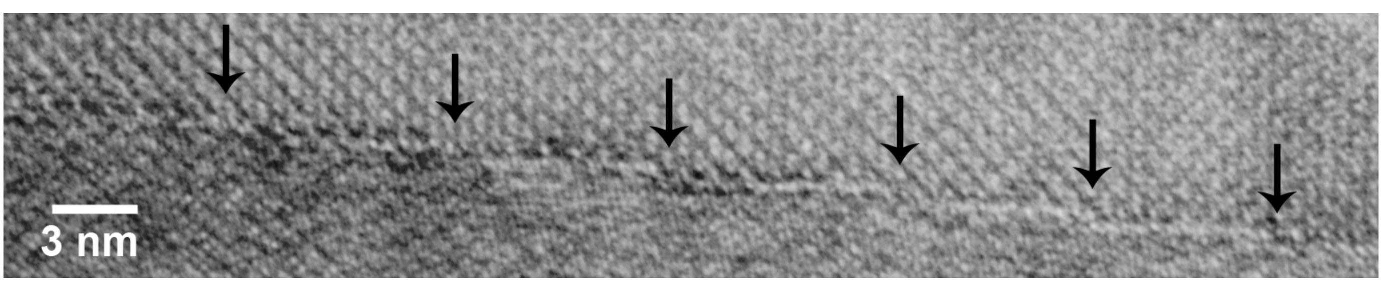

Figure 4. HRTEM image of the interface showing terraces and ledges. Ledges are marked with black arrows and terraces are between them.

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