Growth of decagonal quasicrystal phase in laser resolidified Al$_{72}$Ni$_{12}$Co$_{16}$

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Abstract  An ultra-high temperature gradient directional solidification process produced by a widened laser beam was adopted to achieve the directionally solidified microstructure of the stable decagonal quasicrystal phase in Al$_{72}$Ni$_{12}$Co$_{16}$ alloy. X-ray, SEM, TEM and optical microscopy techniques were used to investigate the microstructures and identify the phase. The directionally
solidified decagonal quasicrystal showed the facet morphology and grew in lateral growth mode. The unusual periodic and quasiperiodic atomic structures of the decagonal quasicrystal and the epitaxial growth in the melt pool were considered to be the key factors influencing the growth morphology. The experimental results were consistent with the Toner’s theoretical atomistic growth model.

Keywords: quasicrystal, lateral growth, alloy, directional solidification.

Since the discovery of an icosahedral phase with five-fold symmetry axis diffraction patterns in the melt quenched Al-Mn alloy, a lot of research activities have been devoted to finding new quasicrystals and to clarifying their atomic structure and physical properties due to quasi-periodic structure. In recent years many efforts have been made in fields of theoretical model, description method and manufacturing of high quality single-crystal. After the metastable quasicrystals were discovered in Ti-Fe-Si and Al-Co, the stable ones were discovered in Al-Cu-Fe and Al-Ni-Co systems respectively. The discoveries of these stable quasicrystals have promoted great progress in the studies of atomic structure and physical properties because these alloys have quasicrystal structure without high density of defects and phason strain resulting from rapid solidification. Direct measurement of physical properties of periodic and quasi-periodic structure is meaningful and powerful in clarifying the unusual quasi periodic structure.

The Al-Ni-Co system among decagonal quasicrystals ever found was considered to form a single-grain most easily by slow cooling method. Yokoyama et al. constructed a partial isothermal phase diagram including a decagonal phase in the Al-Ni-Co system, determined the composition of the liquid in equilibrium with the stoichiometric decagonal phase, and produced a decagonal quasicrystal by the Czochralshi method. New physical mechanisms during growth characteristic of quasi-periodicity have been expected to stem from the random state in amorphous materials or the periodic state in crystals. For this structural feature, one can simultaneously compare the physical properties for both directions in directionally solidified decagonal quasicrystal. Thus, it is obviously advantageous to performing experiments of studying the growth mechanism of the decagonal quasicrystal phase. Pan et al. have developed ultra-high temperature gradient directional solidification with a wide range of G/R ratios between gradient temperature (G) and growth rate (R) produced by a laser beam for a slice placed on a thick ceramic plate. Under the circumstances the high temperature gradient in the melt could significantly refine the solidification microstructure and considerably reduce the microsegregation degree of the solidified materials. It has the benefits of directionally solidified microstructure with a preferred orientation formation and no nucleation involved (i.e. similar to epitaxial growth). Therefore, this process could be effectively adopted to investigate the growth mechanism of a quasicrystal.

1 Experiment

High-purity aluminum, nickel and cobalt (all 99.99% purity above) were taken in the required composition to form an alloy having a stoichiometry of Al\textsubscript{72}Ni\textsubscript{12}Co\textsubscript{16}. The process of melting was carried out in a vacuum arc furnace under argon atmosphere, to produce a button approximately 4 cm in diameter which was remelted four times to achieve complete homogenization.

The laser resolidification experiment was carried in a Rofin-Sinar 850 continuous wave CO\textsubscript{2} laser. Table 1 lists the process parameters. The specimen was polished up to 1000 grade SiC emery paper and thoroughly cleaned in methanol prior to laser treatment. The melted pool was shielded to prevent oxidation by blowing high-pressure helium over the surface during treatment.

<table>
<thead>
<tr>
<th>Power/kW</th>
<th>Sample size/mm</th>
<th>Beam diameter/mm</th>
<th>Scanning velocity/mm s\textsuperscript{-1}</th>
<th>Shielding gas discharge/L s\textsuperscript{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>4\times0.4\times10</td>
<td>1.5</td>
<td>345.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Crystallographic feature was mainly examined by Rigaku X-ray power diffractometer with a CuK\textsubscript{\alpha} source. The slice was electrolytically thinned using an electrolyte of 5% HClO\textsubscript{4} in ethanol at −30°C and investigated in a JEM-200CX electron microscope. Microstructure observation was carried on a JXA-840 scanning electron microscope.