High-pressure x-ray diffraction of icosahedral Zr-Al-Ni-Cu-Ag quasicrystals

Jiang, Jianzhong; Saksl, Karel; Rasmussen, Helge Kildahl; Watanuki, T.; Ishimatsu, N.; Shimomara, O.

Published in:
Applied Physics Letters

Link to article, DOI:
10.1063/1.1394951

Publication date:
2001

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
High-pressure x-ray diffraction of icosahedral Zr–Al–Ni–Cu–Ag quasicrystals

J. Z. Jiang, a) K. Saksl, and H. Rasmussen

Department of Physics, Building 307, Technical University of Denmark, DK-2800 Lyngby, Denmark

T. Watanuki, N. Ishimatsu, and O. Shimomara

Synchrotron Radiation Research Center, Japan Atomic Energy Research Institute, Mikazuki, Hyogo 679-5148, Japan

(Received 14 May 2001; accepted for publication 24 June 2001)

The effect of pressure on the structural stability of icosahedral Zr–Al–Ni–Cu–Ag quasicrystals forming from a Zr_{65}Al_{7.5}Ni_{10}Cu_{7.5}Ag_{10} metallic glass with a supercooled liquid region of 44 K has been investigated by in situ high-pressure angle-dispersive x-ray powder diffraction at ambient temperature using synchrotron radiation. The icosahedral quasicrystal structure is retained up to the highest hydrostatic pressure used (approximately 28 GPa) and is reversible after decompression. The bulk modulus at zero pressure and its pressure derivative of the icosahedral Zr–Al–Ni–Cu–Ag quasicrystal are 99.10±1.26 GPa and 4.25±0.16, respectively. The compression behavior of different Bragg peaks is isotropic and the full width at half maximum of each peak remains almost unchanged during compression, indicating no anisotropic elasticity and no defects in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals induced by pressure. © 2001 American Institute of Physics.

DOI: 10.1063/1.1394951

Recently, after the discovery of the formation of icosahedral quasicrystals from Zr–Al–Cu–Ni metallic glasses,1 quasicrystals have been found by crystallization in many Zrbased alloy systems, such as ZrM (M=Pd and Pt),2,3 ZrNiM (M=Pd, Au, Pt, and Ti),4,5 ZrCuM (Al and Pd),6,7 ZrAlCuPd,7 ZrCuNiPd,7 ZrAlNiM (M=Cu, Pd, Au, and Pt),8–10 ZrAlNiCuM (M=Ti, Au, Pt, Pd, and Ag),11–17 and ZrTiCuNiBe.18 Inoue and co-workers15 further found that bulk quasicrystalline ZrAlNiCuM (M=Pd and Ag) alloys exhibit high strength and good ductility. The formation of quasicrystals in these alloys becomes very interesting. It has been demonstrated from several groups that Zr-based quasicrystals have a phase transformation into intermetallic compound(s) at high temperatures. In this work, we report the structural stability of the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals forming from a Zr_{65}Al_{7.5}Ni_{10}Cu_{7.5}Ag_{10} metallic glass under hydrostatic pressure up to approximately 28 GPa by in situ high-pressure angle-dispersive x-ray powder diffraction (XRD) at ambient temperature using synchrotron radiation. It should be mentioned that stable quasicrystals against higher pressures on various conventional Al- and Ti-based systems have been reported.19–26 In most cases, the full width at half maximum (FWHM) of the Bragg peaks increases with pressure. It was suggested that the defects induced during compression stabilize the quasicrystalline structure. However, the results obtained here show that the quasicrystalline structure could be intrinsically stable during compression of about 17% volume contraction.

A ribbon sample of the Zr_{65}Al_{7.5}Ni_{10}Cu_{7.5}Ag_{10} metallic glass with a cross section of 0.03 mm×1 mm was prepared by the melt-spinning technique from a master alloy ingot prepared by arc melting in an Ar atmosphere. Thermal analysis of the as-prepared amorphous ribbon was performed in a differential scanning calorimeter (DSC) at a heating rate of 3 K/min under a flow of purified argon. The alloy exhibits an endothermic event characteristic of the glass transition \( T_g \approx 628 \) K, followed by two characteristic exothermic events \( T_{x1} = 672 \) K and \( T_{x2} = 730 \) K, and 34.1 and 40.4 J/g, respectively, indicating two-stage amorphous-to-quasicrystalline and quasicrystalline-to-intermetallic phase transformation processes, which are consistent with data reported in the literature for the alloy.11–17 Subsequent annealing for preparation of Zr-based quasicrystals was performed on the as-quenched amorphous ribbon in a vacuum of \( 1 \times 10^{-6} \) Torr at 663 K for 2 h. The icosahedral quasicrystalline structure of the annealed sample was confirmed by x-ray powder diffraction and transmission electron microscopy. The average grain size of the icosahedral quasicrystals was approximately 45 nm. A flake (approximately 20 \( \mu \)m) of the annealed sample was loaded into a diamond-anvil cell with a Re gasket of 150 \( \mu \)m in hole. In order to insure the hydrostatic conditions up to 30 GPa, liquid He (2000 atm) was used as the pressure transmitting medium. The actual pressure was calculated from the wavelength shift of the ruby line using the nonlinear pressure scale of Mao et al.27 In situ high-pressure angle-dispersive x-ray powder diffraction measurements of the annealed sample were performed at the BL10XU beamline, SPring8, Japan, with a wavelength of 0.49592 Å. The diffraction patterns were recorded using an image plate, which provides complete information in the form of a possible preferential orientation of diffracting grains and a better sample averaging by integrating the Debye–Sherrer rings by means of a two-dimensional data analysis program.

A large number of XRD patterns were recorded at pressures ranging from 0 to approximately 28 GPa at ambient temperature. In the annealed sample, the two-dimensional diffraction patterns recorded did not show any preferential...
pressed by q ambient pressure is found to be is the quasilattice constant. The quasilattice constant at the golden mean, 1.618. As an example, the new peak is found at q~ at higher two theta angles lattice vector. The Bragg peaks shift monotonously to the right as pressure increases, as shown in Fig. 2 for the three most or lower peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals. Figure 3 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

In conclusion, the effect of hydrostatic pressure (up to 28 GPa; (2) no defect, dislocation, and phason were induced during compression; and (3) no preferential orientation of any symmetry lines was detected during compression. A question of particular interest is whether the sample exhibits anisotropic elasticity. To address this question, we have plotted the compressibility, in our case V(P)/V(P = 0) was taken to be equal to (d(P)/d(P = 0))^3. for the three most distinguishable Bragg peaks (100000, 110000, 101000) as a function of pressure. Table I lists the zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for the Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation. Figure 4 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

Zr–Al–Ni–Cu–Ag quasicrystals are intrinsically stable up to 28 GPa; (2) no defect, dislocation, and phason were induced during compression; and (3) no preferential orientation of any symmetry lines was detected during compression. A question of particular interest is whether the sample exhibits anisotropic elasticity. To address this question, we have plotted the compressibility, in our case V(P)/V(P = 0) was taken to be equal to (d(P)/d(P = 0))^3. for the three most distinguishable Bragg peaks (100000, 110000, 101000) as a function of pressure. Table I lists the zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for the Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation. Figure 4 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

In conclusion, the effect of hydrostatic pressure (up to 28 GPa; (2) no defect, dislocation, and phason were induced during compression; and (3) no preferential orientation of any symmetry lines was detected during compression. A question of particular interest is whether the sample exhibits anisotropic elasticity. To address this question, we have plotted the compressibility, in our case V(P)/V(P = 0) was taken to be equal to (d(P)/d(P = 0))^3. for the three most distinguishable Bragg peaks (100000, 110000, 101000) as a function of pressure. Table I lists the zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for the Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation. Figure 4 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

In conclusion, the effect of hydrostatic pressure (up to 28 GPa; (2) no defect, dislocation, and phason were induced during compression; and (3) no preferential orientation of any symmetry lines was detected during compression. A question of particular interest is whether the sample exhibits anisotropic elasticity. To address this question, we have plotted the compressibility, in our case V(P)/V(P = 0) was taken to be equal to (d(P)/d(P = 0))^3. for the three most distinguishable Bragg peaks (100000, 110000, 101000) as a function of pressure. Table I lists the zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for the Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation. Figure 4 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

In conclusion, the effect of hydrostatic pressure (up to 28 GPa; (2) no defect, dislocation, and phason were induced during compression; and (3) no preferential orientation of any symmetry lines was detected during compression. A question of particular interest is whether the sample exhibits anisotropic elasticity. To address this question, we have plotted the compressibility, in our case V(P)/V(P = 0) was taken to be equal to (d(P)/d(P = 0))^3. for the three most distinguishable Bragg peaks (100000, 110000, 101000) as a function of pressure. Table I lists the zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for the Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation. Figure 4 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

In conclusion, the effect of hydrostatic pressure (up to 28 GPa; (2) no defect, dislocation, and phason were induced during compression; and (3) no preferential orientation of any symmetry lines was detected during compression. A question of particular interest is whether the sample exhibits anisotropic elasticity. To address this question, we have plotted the compressibility, in our case V(P)/V(P = 0) was taken to be equal to (d(P)/d(P = 0))^3. for the three most distinguishable Bragg peaks (100000, 110000, 101000) as a function of pressure. Table I lists the zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for the Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation. Figure 4 plots compression data obtained by averaging the three Bragg peaks. It is clear that the compressibility is equivalent in all directions within experimental uncertainty. This infers no distinguishable anisotropies in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals.

Table I. Zero-pressure bulk modulus (B0) and its pressure derivative (B0′) for three Bragg peaks as well as the averaged values of the three peaks for the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals using the Birch–Murnaghan equation, together with data reported in the literature.

<table>
<thead>
<tr>
<th>Material</th>
<th>B0 (GPa)</th>
<th>B0′ (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al–Cu–Fe</td>
<td>155</td>
<td>2</td>
</tr>
<tr>
<td>Al–Pd–Mn</td>
<td>128</td>
<td>4.2</td>
</tr>
<tr>
<td>Al–Cu–Ru</td>
<td>128</td>
<td>5</td>
</tr>
<tr>
<td>Al–Pd–Re</td>
<td>180</td>
<td>5</td>
</tr>
<tr>
<td>Al–Ni–Co</td>
<td>120</td>
<td>5</td>
</tr>
<tr>
<td>Al–Pd–Mn</td>
<td>100±12</td>
<td>5.3±0.9</td>
</tr>
<tr>
<td>Ti–Zr–Ni–Hf</td>
<td>130±10</td>
<td>5.5±1</td>
</tr>
<tr>
<td>Ti–Zr–Ni–Co</td>
<td>105±10</td>
<td>5.5±1</td>
</tr>
<tr>
<td>Average</td>
<td>99.10±1.26</td>
<td>4.25±0.16</td>
</tr>
</tbody>
</table>


References:
1 Reference 20.
2 Reference 21.
3 Reference 22.
4 Reference 23.
5 Reference 24.
6 Reference 25.
7 Reference 26.
approximately 28 GPa on the structural stability of the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals forming from a Zr_{60}Al_{15}Ni_{10}Cu_{7.5}Ag_{10} metallic glass has been investigated by in situ angle-dispersive x-ray powder diffraction at ambient temperature using synchrotron radiation. It is found that the icosahedral quasicrystalline structure in the sample is intrinsically stable up to 28 GPa. The bulk modulus at zero pressure and its pressure derivative of the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals is 99.10 ± 1.26 GPa and 4.25 ± 0.16, respectively. The compression behavior of different Bragg peaks is isotropic and the full width at half maximum of each peak remains almost unchanged during compression, indicating no anisotropic elasticity and no defects in the icosahedral Zr–Al–Ni–Cu–Ag quasicrystals induced by pressure.

The authors would like to thank Spring8 in Japan for use of the synchrotron radiation facilities. Financial support from the Danish Technical Research Council, the Danish Natural Sciences Research Council, and SPring8 is gratefully acknowledged.