THE STRUCTURE OF AN AMORPHOUS SUPERCONDUCTOR, LANTHANUM-GOLD

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Professor Pol Duwez, principal investigator.

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I. INTRODUCTION

This note reports a structural study on $\text{La}_{80}\text{Au}_{20}$ produced by rapid-quenching from the liquid state.¹ Other amorphous superconductors have been produced by vapor deposition.^{2, 3, 4} The alloy appears to be an ideal type II superconductor (Ginzburg-Landau parameter ~ 70) (5) with a sharp (0.2°K) transition temperature at 3.5°K , which indicates the alloy is quite homogeneous on the scale of the coherence length ($\sim 90\text{\AA}$). The critical current at zero field is 10^4 amp/cm^2 , and there is a linear variation of the upper critical field with temperature. The composition range for the amorphous structure is 18 to 26 atomic % gold.

II. EXPERIMENT

The alloy was prepared by induction melting on a silver boat under argon atmosphere. Foils (60μ thick) were quenched by the piston and anvil technique.⁶ The density was measured by hydrostatic weighing.⁷ The x-ray apparatus, data collection and analysis techniques are described elsewhere.^{8, 9} It was necessary to mount three foils together in order to intercept the entire x-ray beam.* During the 4-days of data collection, minor surface oxidation occurred; and after one month, the specimens had disintegrated from oxidation.

Corrections to the data included background, polarization, multiple scattering, and Compton modified radiation. The data was converted from arbitrary units into electron units by the high-angle normalization method.¹⁰ The reduced intensity $k_i(k)$ ($k = 4\pi\sin\theta/\lambda$) is shown in

Figure 1. $W(r)$, Figure 2, is obtained by Fourier transformation,

$$W(r) = \frac{2r}{\pi} \int_0^{17.4\text{\AA}} k i(k) \sin(kr) \exp(-0.01k^2) dk$$

The radial distribution function is, $RDF = 4\pi r^2 \rho(r) = 4\pi r^2 \rho_0 + W(r)$;
 $\rho_0 = 7.36 \pm 0.03$ gm/cc. For a binary alloy

$$\rho(r) = 0.67 \rho_{\text{La-La}} + 1.96 \rho_{\text{La-Au}} + 0.36 \rho_{\text{Au-Au}},$$

where the partial density functions, ρ_{ij} , are the number of j -type atoms per unit volume at distance r from an i -type atom, and the constants are the average weight factors¹¹ computed from the atom fractions and dispersion corrected scattering factors of the elements.¹² The first peak in the RDF appears to contain only contributions from $\rho_{\text{La-Au}}$ and $\rho_{\text{La-La}}$, since the position of the maxima (3.33 and $3.75 \pm 0.05\text{\AA}$) correspond to the La-Au and La-La distances (3.31 , and $3.74\text{\AA}$) computed from the Goldschmidt radii. The leading edge of the smaller La-Au peak is approximately Gaussian, and a reflection about an axis at $3.33\text{\AA}$ allows computation of its area. This area was subtracted from the total area, up to the minimum at $4.5\text{\AA}$, to obtain the area under the $\rho_{\text{La-La}}$ peak. These areas together with the weight factors yield the La-Au coordination number, 2.9 , and the La-La coordination number, 8.1 . The estimated error in these values from termination and k -dependent errors is $\leq \pm 0.5$.

Fig. 1. The reduced intensity $k_i(k)$, of amorphous La-Au damped by a factor of $\exp(-0.01k^2)$.

Fig. 2. The function $W(r)$.

Fig. 3. The radial distribution function.

III. DISCUSSION

Two important features of crystalline La_2Au (Table I)¹³ are the La-Au distance is, on average, smaller than the La-La distance; and there are no Au-Au neighbors within $4.4\text{\AA}$. This compositional short range order appears to be maintained in the glass. The glass has a range of interatomic distances characterized by a full width at half maximum of $0.36\text{\AA}$ for the La-Au peak and $0.68\text{\AA}$ for the La-La peak. This is typical of other glassy systems.^{14, 15} Although no pronounced splitting occurs in the second peak of the RDF, it appears to be the superposition of at least two peaks centered at 5.90 and $6.97\text{\AA}$. The lack of definition in these peaks makes the quoted positions only rough estimates. The weak correlation beyond first neighbors is observed in other amorphous rare-earth alloys.^{16, 17} This suggests either there is no significant order outside the first shell, or the weighted partial density functions combine into a broad second peak; each component representing a well-defined order out to second nearest neighbors. There is some hope for further defining this structure by the method of extended x-ray absorption fine structure.¹⁸

Finally, consider the relation between the structure and superconducting properties. The disordered structure implies a short electron mean free path and therefore a short coherence length.¹ Taking another viewpoint, the superconducting properties may provide unique information on the defect structure of the glass. For the glass, the critical current varies smoothly with applied field and demonstrates reversibility with no evidence of flux pinning. This is not observed for the crystal, and flux pinning does occur.⁵ This result suggests that

TABLE I

Interatomic Distance and Coordination Number (CN) for crystalline La_2Au

The distance is followed in parenthesis by the number of neighbors.

neigh- bor atom site	La I	La II	Au	CN (= no. La + no. Au) within $4.3\text{\AA}$
La I	3.61(2)	3.54(1), 3.64(2) 3.70(2), 3.76(1)	3.02(2), 3.11(2) 4.42(1)	8 + 4
La II	3.54(1), 3.64(2) 3.70(2), 3.76(1)	4.21(2)	3.28(3), 3.65(2)	8 + 5
Au	3.02(2), 3.11(2) 4.42(1)	3.28(3), 3.65(2)	4.46(2), 4.53(2)	9 + 0

amorphous La-Au is an ideal type II superconductor and implies that dislocations and other microstructure may not exist in the glass. Flux pinning by dislocations and other substructure is firmly established²⁰; however the superconducting properties are often a sensitive function of the cold work and annealing.²¹ For this reason, further tests are needed to confirm the ideal type II behavior.

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