Enhanced superconductivity and lattice instability in Nb-Rh alloys*

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(Received 15 January 1975)

Superconductivity with transition temperature above 10 °K has been observed in a new Nb-Rh intermediate phase. The new metastable phase is obtained by liquid quenching the binary alloy or by the addition of a small percentage of carbon to form a stable ternary alloy.

PACS numbers: 74.10., 74.50.D

Superconductivity in the intermediate phases of Nb-Rh has been previously investigated. In this alloy system, the maximum transition temperature reported was that of the σ phase ($T_c = 4.04$ °K).[1] In this paper, we report superconductivity with T_c above 10 °K for metastable Nb-Rb alloys with compositions on the Rh-rich side of the σ-phase field (Fig. 1). The new phase has a cubic structure with $a = 11.89$ Å.[2] Samples showing T_c enhancements were obtained by two methods. The first employs rapid cooling from the liquid state which permits retention of the metastable high-temperature phase. The second involves the addition of a small percentage of carbon to the binary alloys with subsequent heat treatment.

The alloys were prepared by induction melting of the constituents on a silver boat under an argon atmosphere. Each ingot was remelted several times. Subsequent annealing was carried out in evacuated quartz tubes. Weight loss during the preparation process was less than 0.1% for all alloys. The liquid-quenched samples were prepared following a technique described in Ref. 3. The crystal structure of all phases were obtained from x-ray diffraction analysis. Lattice parameters were calculated from Debye-Sherrer films using the Nelson-Riley extrapolation function. The T_c of the as-cast and annealed ingots were determined using a standard inductance bridge technique, whereas the T_c of quenched foils were determined both from electrical resistance and inductance measurements.

Alloys of the form $Nb_{100-x}Rh_x$ were studied in the compositional range $35 \leq x \leq 50$. The enhancement effect was observed for alloys on the Rh-rich side of the σ-phase field ($x \approx 42$) as shown in Fig. 1. As-cast alloys prepared at this composition had $T_c \approx 4$ °K in agreement with a previous report.[1] For the quenched samples, a broad transition (4–8.8 °K) was observed. X-ray analysis of these samples indicates the presence of a σ phase (lattice parameters $a = 9.79$ Å, $c = 5.05$ Å), an α_2 phase ($a = 4.03$ Å, $c = 3.81$ Å), and several unidentified x-ray lines. Annealing the quenched sample at 850 °C for several days led to a higher transition temperature (transition width = 1 °K, and onset temperature $T_c' = 10.2$ °K). An increased intensity in the unidentified x-ray lines was observed for these annealed samples. Annealing at higher temperature (~950 °C) resulted in the degradation of superconductivity ($T_c' \approx 7$ °K).

To investigate the possibility of stabilizing this high T_c metastable phase, small percentages of several third consituents (C, Ge, O, Si) were added to the binary alloy $Nb_{58}Rh_{42}$. The stabilization was achieved in the alloy $(Nb_{58}Rh_{42})_{97}C_3$. No T_c enhancement was observed for the as-cast sample. A sharp transition characteristic of a single phase ($T_c = 10.3$ °K) was observed after annealing the sample at 1150 °C for 24 h. X-ray analysis of the as-cast sample showed the presence of the σ phase and the α_2 phase as in the as-cast binary $Nb_{58}Rh_{42}$ alloys. The annealed sample contained a trace of the α_2 phase along with a second cubic phase with $a = 11.89$ Å. Comparison of the x-ray patterns of the quenched $Nb_{58}Rh_{42}$ sample and that of the annealed $(Nb_{58}Rh_{42})_{97}C_3$ alloys shows the new phase to be present in both, the unidentified x-ray lines of the quenched alloys being those of the new phase. The observed extinctions in the x-ray pattern of the new phase are compatible with the space group *Fd3m*. This phase is metastable in the binary system and can only be obtained by liquid quenching, whereas the addition of carbon permits its formation under equilibrium conditions in the ternary system. Attempts to prepare this phase by adding a small percentage of other constituents (Ge, O, Si) were unsucessful.

It has been suggested that a Batterman-Barrett-like transformation at high temperatures reduces the T_c in the σ-phase alloys.[4] The Nb-Rh σ phase has unidimensional Nb chains and is tetragonal but with $c/a \sim 0.52$. These suggest the possibility of raising the T_c in the Nb-Rh alloys by retaining the structural instability

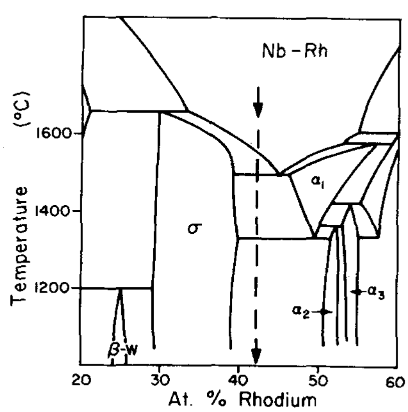

FIG. 1. The phase diagram of Nb-Rh showing the σ-phase and α-phases fields. The vertical dashed line indicates the composition at which the new phase is obtained by rapid cooling.

associated with a high-temperature phase of higher symmetry. In the present case, such instability has been retained in the new cubic phase of the liquid-quenched $Nb_{58}Rh_{42}$ and annealed $(Nb_{58}Rh_{42})_{97}C_3$ alloys with enhanced T_c. It is interesting to investigate the possibility of stabilizing similar phases in other alloys systems; such experiments are underway in this laboratory.

The authors wish to thank Professor Pol Duwez for his advice and encouragement throughout this work.

*Work supported by the U.S. Atomic Energy.

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