Sample dependence of superconductivity for $V_3Si$ under high pressure

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Abstract. $V_3Si$ is one of the superconducting A15 compounds and has relatively high $T_c = 17 \text{ K}$ at ambient pressure. The superconductivity of $V_3Si$ and the pressure effect of that were strongly dependent on the sample. The pressure dependence of $T_c$ was considered to be influenced by the composition and the crystal disorder.

1. Introduction

In many superconductors, a structural phase transition seems to play the important roles in their appearance of superconductivity, but it is still unclear. The difficulty may be arisen from the difference between their transition temperature, for example, the superconducting transition occurs at much lower temperature than the structural phase transition temperature [1].

$V_3Si$ crystallizes in the A15 crystal structure with a cubic unit cell. The Si atoms form a bcc lattice and each cube face is bisected by orthogonal V chains. The importance of these chains is often emphasized to understand qualitatively the generally high critical temperatures of A15 compounds. The superconductivity of $V_3Si$, which is one of the A15 compounds had been already observed at relatively high $T_c = 17 \text{ K}$ [2]. That superconductivity also appears near the lattice instability, martensitic transition at 21 K [3,4]. $V_3Si$ is expected to be the good sample to study the relationship between a superconductivity and a structural instability. However, there are two types of crystals in $V_3Si$, transforming (T) and nontransforming (NT) ones and the difference of these two crystals is not yet understood. In previous works, the pressure dependence of $T_c$ and $T_M$ for both single crystalline samples were investigated up to 3 GPa by Chu et al [3,4]. These studies reported that the pressure dependence of $T_c$ for T and NT samples was different above 2.5 GPa. $T_c$ of T sample monotonically increased and of NT sample suddenly decreased above 2.5 GPa. We investigated the pressure dependence of $T_c$ for NT polycrystalline sample and the pressure dependence of $T_c$ was different from the reports of Chu et al [5].

In this work, we focus on the sample dependence of the pressure effect of the superconductivity for $V_3Si$.

2. Experimental details

Two $V_{1-x}Si_x$ samples used in this work were prepared by arc melting the commercial $V_3Si$ polycrystalline sample (purity: 99.9%). The compositions of them were controlled by changing
the arc melting time. The melting point of V₃Si is over 1900 °C and the vapor pressure of silicon around this temperature is 10 times higher than that of vanadium. The longer the arc melting time is extended, the more silicon evaporates. One sample grown by melting for about 20 minutes was the same with the sample used in our previous work could be Si-poor sample [5]. The other sample was made by melting for several minutes. The x-ray fluorescence analysis and the powder x-ray diffraction analysis were done for both samples to investigate the composition and the crystal structure. $T_c$ of them at ambient pressure were determined by the electrical resistivity measurement. The specific heat was measured for the sample arc melted for 3 minutes by means of the ac-calorimetric method. Two Au/AuFe (0.07%) thermocouples were used as the heater and the thermometer, respectively. Pressure was applied using a diamond anvil cell (DAC) with glycerol as a pressure transmitting medium under pressures up to 2.5 GPa.

3. Experimental results

From the results of the x-ray fluorescence analysis, the compositions of two samples were $V_{1-x}Si_x$ at $x = 0.15$ (Sample 1) and 0.25 (Sample 2). The atomic Si content $x$ for Sample 1 was the average of the total composition, V₃Si and the parasitic component which was revealed by the x-ray diffraction analysis (mentioned below). According to V-Si binary phase diagram, V₃Si can exist in the composition range of $0.22 < x < 0.25$ [6]. Sample 1 was considered to be the Si-poor crystal within the composition range.

The x-ray diffraction (XRD) patterns showed that Sample 1 was the mixture of V₃Si and the other structural parasitic component (Fig 1). Any stoichiometric compounds in V-Si binary phase diagram doesn’t reproduce the experimental diffraction pattern. The XRD pattern of

![Figure 1](image1.png)

**Figure 1.** X-ray diffraction pattern of V₃Si; Sample 1 (Si-poor), Sample 2 (stoichiometric).

![Figure 2](image2.png)

**Figure 2.** Temperature dependence of the electrical resistivity of V₃Si; Sample 1 (Si-poor), Sample 2 (stoichiometric).
Sample 2 shows that Sample 2 doesn’t contain any impurities. The lattice parameters of V$_3$Si were 4.738 Å and 4.741 Å for Sample 1, 2, respectively. The results were consistent with the previous report that the lattice parameter of V$_{1-x}$Si$_x$ was independent of the composition around $x = 0.25$ [7].

Figure 2 shows the temperature dependence of the electrical resistivity for two samples. The residual resistance ratio were $\text{RRR} = \rho (300 \text{ K}) / \rho (18 \text{ K}) = 20, 10$ for Sample 1, 2, respectively. It is possible that RRR of Sample 1 is determined mainly by the parasitic components. It is unclear what caused the relatively low $T_c$ of Sample 2. The relationship between $T_c$ and RRR has not been understood. And $T_c$ is independent of the composition near stoichiometry in the previous report [7]. It is considered that there are some other important factors that determine $T_c$ of V$_3$Si. Table 1 is the overview of Sample 1, 2.

Table 1. Atomic Si content, lattice parameter (a), electrical resistivity ($\rho$) at room temperature, and $T_c$ of Sample 1, 2.

|          | atomic Si content | $a$ (Å) | $\rho$ ($\mu\Omega\cdot\text{cm}$) | $T_c$ (K) |
|----------|------------------|--------|-------------------------------|----------|
| Sample 1 | 15%              | 4.738  | 98                            | 17.1     |
| Sample 2 | 25%              | 4.741  | 89                            | 16.3     |

Figure 3 shows the temperature dependence of the specific heat for Sample 2 at several pressures. $T_c$ was determined from the half height of the jumps. The jumps of the specific heat becomes smaller with applying pressure. $T_c$ was lower than that determined by the electrical resistivity measurement at ambient pressure and decreased with applying pressure up to 2.5 GPa. The discrepancy of $T_c$ is not caused by the sample heating in the ac-calorimetric measurement. We confirmed that the sample temperature changed little by the application of heat at a certain temperature around $T_c$. The relatively low RRR and the broad superconducting transitions are considered to be influenced by the sample inhomogeneity. And it is possible that the low $T_c$ and the discrepancy of $T_c$ for Sample 2 are also caused by the same reason and the quality of the sample is rather poor. Figure 4 shows the pressure dependence of $T_c$ for V$_3$Si NT crystals. The pressure dependence of $T_c$ are positive and negative for Sample 1, 2 respectively, and different from the reports of Chu et al [4]. $T_c$ of Sample 1 determined by the electrical resistivity measurement (not shown here) are consistent with the results of the ac-susceptibility measurement for Sample 1 [5]. The difference of the pressure dependence of $T_c$ is expected to be influenced by each sample’s composition. But we couldn’t find the synthesis process and how Chu’s NT sample was characterized. To reveal the relationship between the
Figure 4. Pressure dependence of $T_c$ for $V_3$Si NT samples. The square, triangle and circle symbols indicate $T_c$ determined by the ac-susceptibility [5], the electrical resistivity and the ac-calorimetric measurements, respectively.

composition and the pressure effect is important to study the superconductivity of $V_3$Si and the other A15 compounds.

There are still unsolved problems of superconductivity under high pressure in A15 compounds including $V_3$Si. The sample growth of $V_3$Si single crystal and further experiments (e.g. thermal expansion measurement) for the sample under high pressure are planned to investigate the mechanism of the pressure dependence of $T_c$ for $V_3$Si.

4. References

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