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# Effect of Ti Concentration on the Growth of $Nb_3Sn$ Between Solid Nb(Ti) and Liquid Sn

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The change in the growth rate of the $Nb_3Sn$ product phase because of Ti addition is studied for solid Nb(Ti)–liquid Sn interactions. The growth rate increased from no Ti to 1 at.% and 2 at.% of Ti in Nb, and the activation energy decreased from 221 kJ/mol to 146 kJ/mol. Based on the estimated values, the role of grain boundary and lattice diffusion is discussed in light of the possibility of increased grain boundary area and point defects such as antisites and vacancies.

**Key words:** $Nb_3Sn$, parabolic growth, activation energy, diffusion mechanism

## INTRODUCTION

The $Nb_3Sn$ superconductor is an integral part of synchrotrons and magnetic fusion reactor technology, especially where a magnetic field higher than 10 T is required, which lies beyond the limit of conventional Nb-Ti superconductors.[1] The performance of these materials is a function of their microstructural features,[2] which themselves are a function of the processing route adopted. $Nb_3Sn$ is a brittle intermetallic compound, and drawing wires directly is impossible. To circumvent this problem, various improvised techniques such as infiltration, surface diffusion, the bronze technique, the internal tin method, and the powder-in-tube process have been developed.[1,3]

Infiltration[1] and surface diffusion[4] techniques involve direct reaction between solid Nb and liquid Sn at elevated temperature to grow the $Nb_3Sn$ product phase. There have been a few attempts to understand the growth of $Nb_3Sn$ during solid Nb–liquid Sn interaction. Old and Macphail[5] conducted experiments at temperatures such that only the $Nb_3Sn$ phase is expected to grow at the interface. However, they reported an unusual behavior that the thickness of the product phase decreased with increase in the annealing temperature. Ronami et al.[6] conducted similar experiments above 1300°C and reported the usual trend of increasing layer thickness with annealing temperature. So, it is necessary to revisit such experiments.

To date, several experimental studies have been conducted to understand the growth behavior of the product phase formed by the bronze technique.[7–17] In this technique, Nb is coupled with Cu(Sn) bronze alloy such that only the $Nb_3Sn$ phase grows at the interface. The effects of alloying of different elements such as Ti, Ta, Zr, and Hf in Nb and Ti, Mg, Ga, and Ge in Cu(Sn) on the growth rate of $Nb_3Sn$ and the superconducting properties have also been studied in detail.[18–24] Particularly, Ti is found to be one of the best alloying additions, not only enhancing the growth rate of the product phase but also increasing the critical flux by an order of magnitude.[25,26] It has been shown that Ti essentially pins the grain boundaries to retard grain growth.[27] Subsequently, the growth rate of the product phase increases owing to increased grain boundary density. Because of the same reason, the critical current density also increases. It is also reported that the critical temperature $T_c$ starts decreasing with no further improvement in the upper critical field, $H_{c_2}$, for more than 2 at.% Ti.[26] However, the effect of alloying has not been examined previously in the case of solid Nb and liquid Sn interaction.

So, the aim of the present study is to estimate the growth rate of the $Nb_3Sn$ product phase during solid Nb–liquid Sn interactions. The temperature is chosen (above 900°C) such that only the $Nb_3Sn$

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