Influence of Chemical Composition on the Functional Properties of $Ni_{50}Mn_{50-x}Sb_x$ Metamagnetic Shape Memory Alloys

Sb addition to AFM $Ni_{50}Mn_{50}$ alloy induces FM interaction and lowers Néel temperature. Dependence of Néel temperature on Sb content was computed for $Ni_{50}Mn_{50-x}Sb_x$ alloys. Temperature-composition phase diagram of $Ni_{50}Mn_{50-x}Sb_x$ system was constructed. Competing AFM and FM interactions lead to a spin glass state. Magnetic ordering significantly affects low-temperature specific heat and electronic coefficient.

Ni-Mn-based magnetic shape memory alloys possess distinctive properties such as the magnetocaloric effect, elastocaloric effect, shape memory effect, superelasticity, and giant magnetoresistance, making them highly promising for various applications. Among these, the Ni-Mn-Z (Z = In, Sn, Sb) system is notable for its rich phase diagram and the possibility to tailor its functional properties through alloying with Z elements. In particular, in $Ni_{50}Mn_{50-x}Z_x$ alloys, the martensitic transformation (MT) occurs at lower Z concentrations, whereas higher Z concentrations keep the alloy in a parent ferromagnetic (FM) austenitic phase. The low-temperature martensitic phase of $Ni_{50}Mn_{50-x}Z_x$ alloys remains a topic of ongoing research.

In this work, we have conducted a comprehensive study on $Ni_{50}Mn_{50-x}Sb_x$ alloys [2]. Through a combination of magnetization experiments, differential scanning calorimetry, low-temperature specific heat measurements, along with its theoretical analysis, we have elucidated the intricate magnetic and electronic properties of this alloy system. Our primary objective has been to unravel the fundamental aspects of magnetic transitions within the Ni-Mn-Sb alloy system. Additionally, we have constructed a temperature-concentration phase diagram for Ni-Mn-Sb alloys, thereby contributing to a more thorough understanding of its phase behavior.

The altering Sb content in $Ni_{50}Mn_{50-x}Sb_x$ alloys induces variations in magnetic interactions and phase transitions. The addition of Sb to $Ni_{50}Mn_{50}$, which is collinear antiferromagnet (AFM) with a high Néel temperature, induces ferromagnetic interaction and leads to the decrease of Néel temperature. The compositional dependence of Néel temperature was computed from magnetic data. Increasing Sb content reduces characteristic temperatures for AFM interaction and elevates characteristic temperatures for FM interaction. Fig. 1 displays the characteristic temperature of AFM (blue region) and FM (red region) interaction in $Ni_{50}Mn_{50-x}Sb_x$ system. The overlap of these regions gives rise to a spin glass state [2]. The blue line corresponds to MT transition temperature. We identified six distinct magnetic phases in the $Ni_{50}Mn_{50-x}Sb_x$ system depending on temperature and Sb concentration as shown in Fig. 1. It includes: antiferromagnetic martensite (AFM M), paramagnetic martensite (PM M), ferromagnetic martensite (FM M), spin glass or blocking state (SG or BS) within the martensitic state, and paramagnetic austenite (PM A) and ferromagnetic austenite (FM A) within the austenitic state.

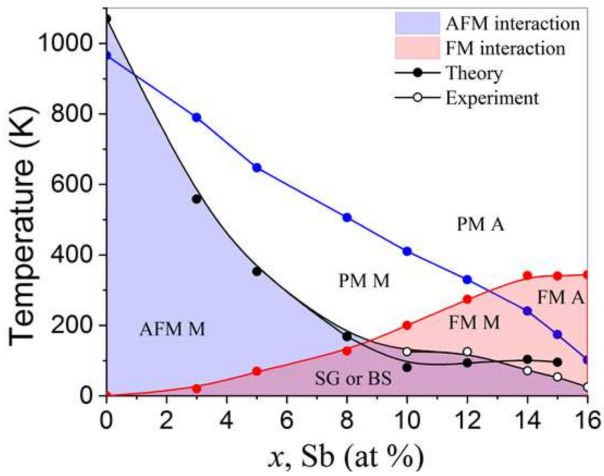

Fig. 1 The AFM (blue region) and FM (red region) interactions in $Ni_{50}Mn_{50-x}Sb_x$ system giving rise to spin glass state (pink region). Characteristic temperatures of AFM interaction: computed (black circles) and estimated from experiments (open circles).

The experimental investigation of low-temperature specific heat of metallic alloys is of considerable significance due to its close connection to the underlying electronic properties. Indeed, the analysis of measurements of low-temperature specific heat is commonly used for the empirical estimation of electronic specific heat coefficient γ and Debye temperature T_D. However, in the case of consideration of magnetic solid the influence of the magnetic ordering should be accurately accounted for the proper estimation of the electronic, lattice, and magnetic contributions to the specific heat [3]. Understanding specific heat behavior in relation to magnetic ordering is crucial for characterizing the thermodynamic and electronic properties of magnetic materials. This influence is especially pronounced for metamagnetic Ni-Mn-Z (Z = In, Sn, Sb) alloys, where the drastic changes in the magnetic characteristics occur depending on Z concentration.

In present work it has been shown that low-temperature specific heat measured for $Ni_{50}Mn_{50-x}Sb_x$ alloys with $x \geq 17$ being in the FM parent state is significantly different from that measured for the alloys, with $x \leq 16$, being in martensitic phase with weak magnetism. Through a detailed experimental analysis and theoretical considerations, we aim to accurately estimate the electronic, magnetic and lattice contributions to low-temperature specific heat and explore the dependence of the γ and T_D on Sb content in both parent and martensite phases [2].

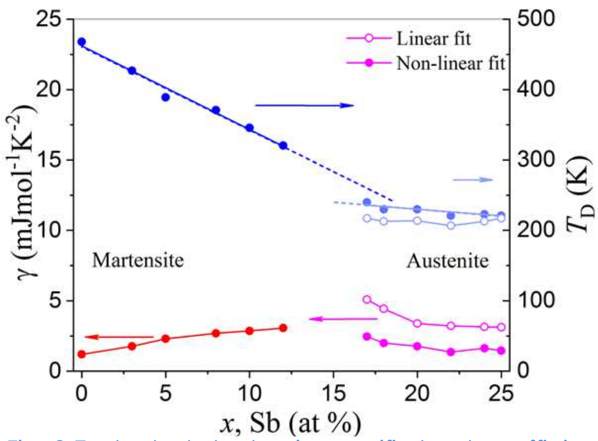

Fig. 2 Evaluated electronic specific heat coefficient γ and Debye temperature T_D of $Ni_{50}Mn_{50-x}Sb_x$ alloys as a function of concentration x. The filled circles show γ and T_D estimated with the account of magnetic contribution to the specific heat (non-linear fit), while the open circles correspond to the linear fit, which disregards the contribution of magnetic system. Lines are guides for eyes.

The procedure for the evaluation of the magnetic part of the specific heat of FM solid was elaborated in [3]. The application of this procedure to different $Ni_{50}Mn_{50-x}Sb_x$ alloys resulted in the concentration dependence of electronic specific heat coefficient and Debye temperature shown in Fig. 2. For the FM austenite region, the filled circles represent the electronic specific heat coefficient and Debye temperature calculated with the account of the magnetic contribution to specific heat (non-linear fit), while open circles denote results from the linear fit, which excludes the magnetic system's contribution. It is seen that disregard of the magnetic contribution in this phase results in an overestimation of the electronic coefficient by a factor of 2 and noticeable underestimation of the Debye temperature.

Importantly, the described behavior may extend to other $Ni_{50}Mn_{50-x}Z_x$ (Z = In, Sn) alloys, where the addition of Z elements leads to the introduction of ferromagnetic interaction.

The results of this collaborative study were published in [2], and support from ICC-IMR was acknowledged.

References

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Keywords: magnetic properties, specific heat, phase transformation
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