Tunable structure and magnetic properties in $Fe_{3-x}V_xGe$ alloys

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ABSTRACT

The structural, magnetic, electrical transport, and mechanical properties of $Fe_{3-x}V_xGe$ intermetallic alloy series ($0 \le x \le 1$) have been investigated. Single phase microstructures are observed for $x < 0.75$. Higher V concentrations $x \ge 0.75$ are multi-phased. Vanadium substitution is observed to induce a diffusionless martensitic phase transformation from a cubic Heusler-like $L2_1$ structure to hexagonal DO_{19} structure, as corroborated by Differential Scanning Calorimetry results. This is completely different from temperature-driven $L1_2$ to DO_{19} transformation of parent compound Fe_3Ge. It has been shown that the addition of V decreases significantly the grain size inhibiting the grain growth by pinning the grain boundary migration. All the alloys in the series are found to be soft ferromagnets at 5K with saturation magnetic moment decreasing as V concentration increases. The low temperature saturation moment is in close agreement with the expected Slater-Pauling values for the cubic $L2_1$ phases, while the hexagonal samples have markedly higher values of saturation moments. The electrical resistivity measured over the temperature range from 5K to 400K shows negative temperature coefficient of resistivity at high temperatures with increasing the V concentration, attributed to impurities at the grain boundaries. Relatively high mechanical hardness values are also observed, with the value increasing with increasing V content.

INTRODUCTION AND MOTIVATION

- Heusler alloys are highly versatile exhibiting a variety of electronic behavior ranging from semiconducting to superconducting and ferromagnetic to non-magnetic.[1]
- For applications in magnetics and spintronics, the inherently low magnetocrystalline anisotropy in cubic Heusler alloys can be limiting factor.
- Identifying a hexagonal Heusler analogue that retains half metallicity and exhibits a high magneto-crystalline anisotropy may be very attractive for applications such as perpendicular media, current perpendicular to plane giant magnetoresistance (CPP-GMR), and spin-torque-transfer RAM (STT-RAM).[2,3]
- V content in $Fe_{3-x}V_xGe$ offers the tunability of the crystal structure from hexagonal to cubic with different magnetic environment.

EXPERIMENTAL

Arc Melting → Heat Treatment → Metallography

Microstructure Analysis
- ❖Grain Formation
- ❑Optical Microscope & SEM

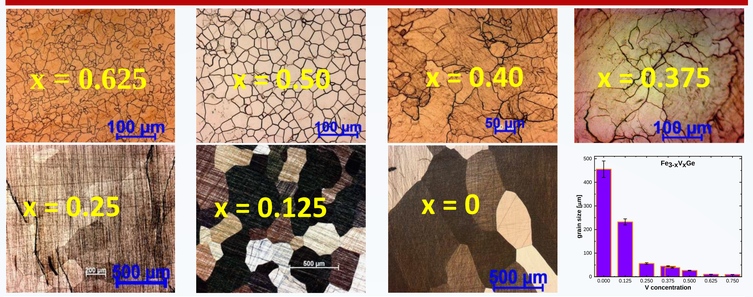
Compositional Analysis
- ❖Stoichiometry & phase distribution
- ❑EDX/EBSD

Structural Analysis
- ❖Crystal Structure and atomic ordering
- ❑XRD

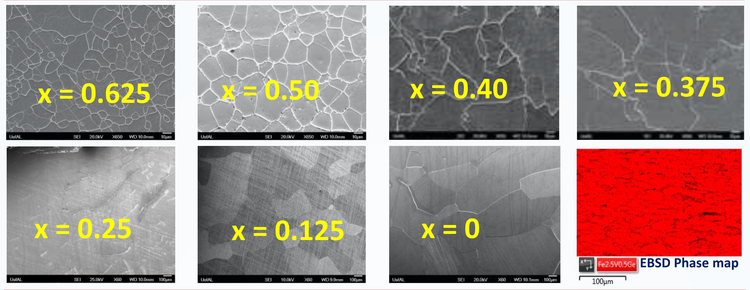
Magnetometry & Transport
- ❖M_s at low temperature, T_c, R(T).
- ❑PPMS

RESULTS AND DISCUSSIONS

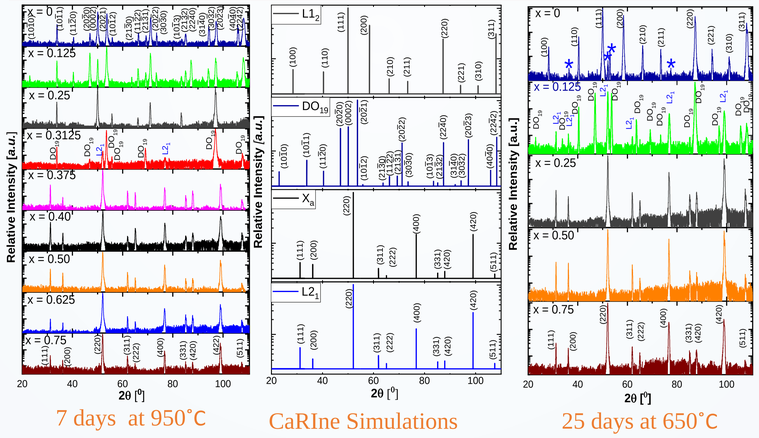
OPTICAL MICROSCOPY



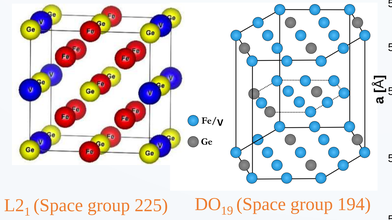
SEM IMAGES



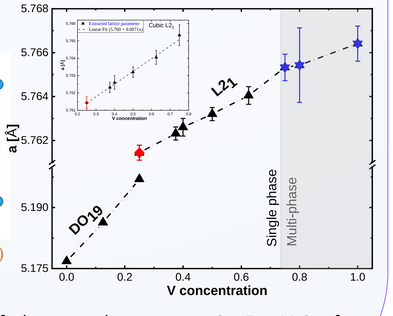
CRYSTAL STRUCTURE



7 days at 950˚C — CaRIne Simulations — 25 days at 650˚C

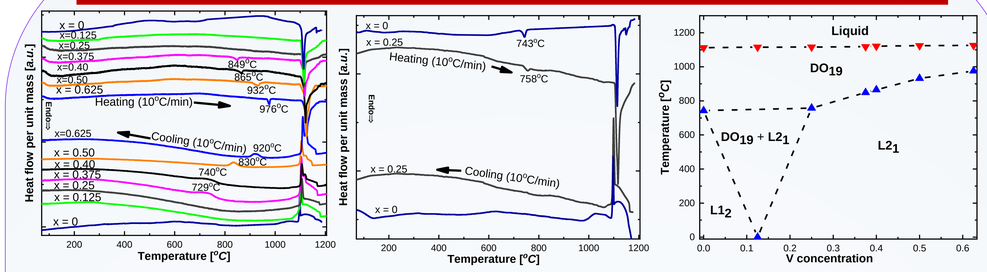


$L2_1$ (Space group 225) DO_{19} (Space group 194)



- V content induces transformation of the crystal structure in $Fe_{3-x}V_xGe$ from hexagonal to cubic, with almost linear increase of lattice parameter in the cubic phase.

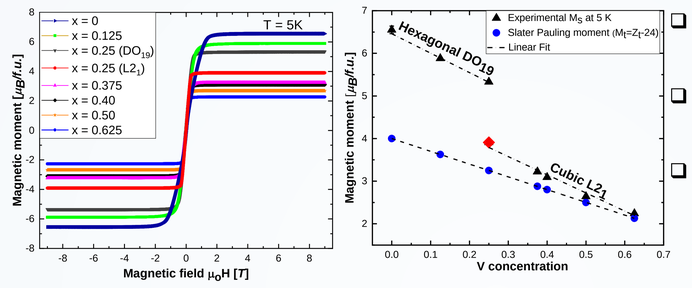
PHASE TRANSFORMATION BEHAVIOR



7 days at 950˚C — 25 days at 650˚C

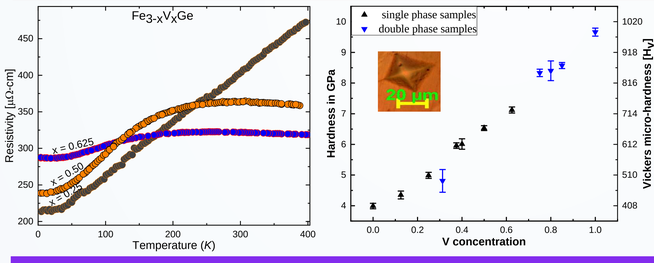
- Small endothermic peaks in the heating cycles, other than prominent melting point peaks correspond to the diffusionless martensitic phase transformation.
- $L2_1$ structure is stabilized over a wide range of temperature with the increase of V content in $Fe_{3-x}V_xGe$.

MAGNETOMETRY



- $Fe_{3-x}V_xGe$ alloys are soft ferromagnets at 5K.
- Magnetic moment of $L2_1$ phases shows linearity with V content.
- Sample with x = 0.25 crystallized in DO_{19} and $L2_1$ structure with different magnetic orderings.

ELECTRICAL TRANSPORT AND MECHANICAL PROPERTIES



- The electrical resistivity shows a negative temperature coefficient of resistivity at high temperatures, more so with increasing the V content.
- V content improves the mechanical hardness.

CONCLUSION

- Single phase polycrystalline bulk $Fe_{3-x}V_xGe$ intermetallic alloys series ($0 \le x \le 0.625$) have synthesized by arc melting.
- Diffusionless $L2_1$ to DO_{19} martensitic phase transformation is observed to depend on V concentration as well as annealing conditions.
- All the alloys are observed to be soft ferromagnets at 5K with different saturation magnetizations at 5K, with the magnetization in the hexagonal phase being substantially larger.
- Anomaly in resistivity is not considered due an order-disorder mechanism or the structural transformation, as the decrease in resistivity occurs even below room temperature, but is presumed to arise from semiconducting Ge-rich material at the grain boundaries.
- Vanadium is found to play a central role in tuning rich physical properties in $Fe_{3-x}V_xGe$, changing the mechanical properties, stabilizing the cubic $L2_1$ structure, not found in the parent Fe_3Ge compound, and shifting the martensitic transformation temperature to higher values compared to that of parent Fe_3Ge.

REFERENCES

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*THE FINANCIAL SUPPORT TO CONDUCT THIS WORK WAS SOURCED FROM NSF DMREF GRANT NUMBER 1235396 AND NSF DMR GRANT NUMBER 1508680.