Magnetic properties of High-entropy alloy

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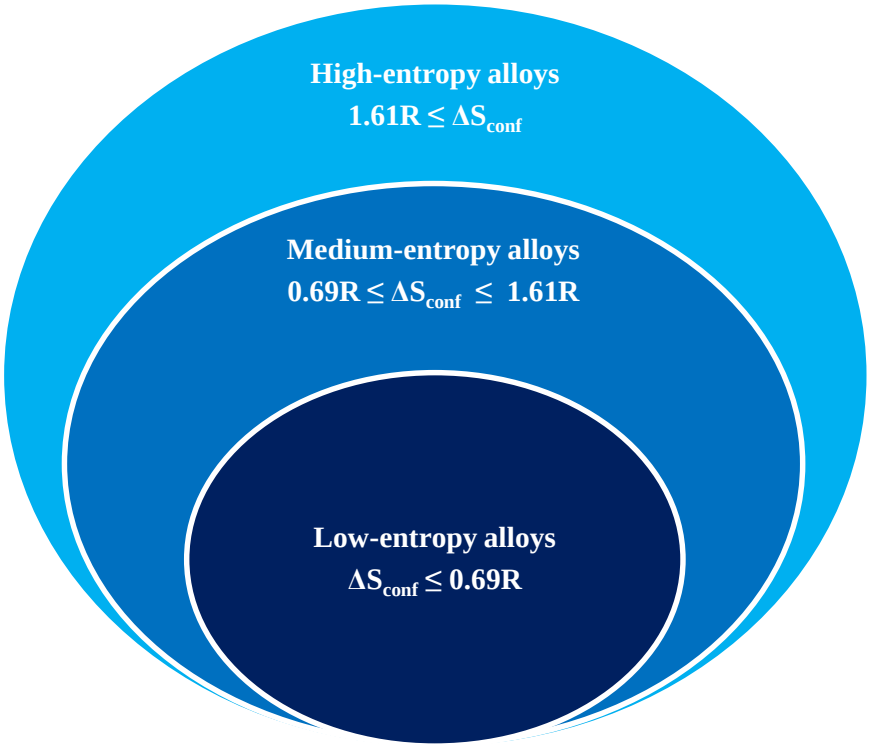
1. High-entropy alloy

❖ Definition

- **They are loosely defined as solid solution alloys that contain more than five principal elements in equal or near equal atomic percent (at.%).**



❖ Characteristics

- **Excellent mechanical properties**
- **High corrosion resistance**
- **HEAs have the single-phase solid solution (FCC, BCC)**

1. High-entropy alloy

◈ **Multi-Principal-Element Effect**

1. High-entropy effect

- **HEAs composed of chemically compatible elements are composed of only a few solid solution phases or even one single phase, which is attributed to their high mixing entropies.**

2. Lattice distortion effect

- **All atoms are solute atoms and their atomic radius are all different from one another. Lattice distortion effects in HEAs cause high solid solution properties.**

3. Sluggish diffusion effect

- **In combination with the lattice distortion which hinders atomic movement will limit the effective diffusion rate in HEAs.**

4. Cocktail effect

- **HEAs can be viewed as an atomic-scale composite. Therefore, they exhibit a composite effect coming from the basic features and interactions among all the elements themselves.**

2. Paper review

High-entropy Alloys with High Saturation Magnetization, Electrical Resistivity, and Malleability

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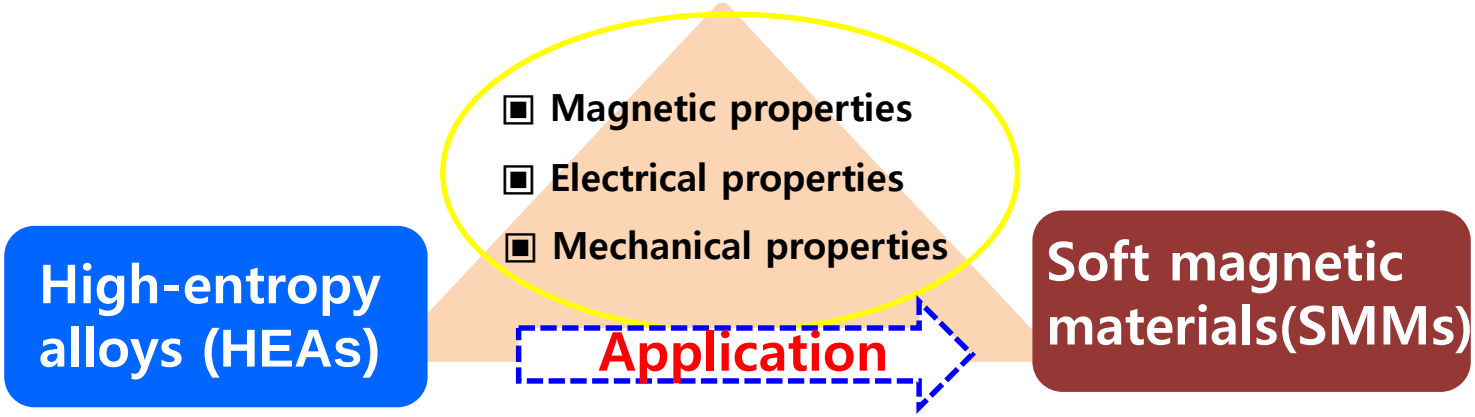


▶ Nature scientific reports 15 March2013

2. Paper review

Requirement for Soft magnetic materials(SMMs)

1. High saturation magnetization
➔ To enhance the capacity

2. High electrical resistivity
➔ To suppress the eddy-current loss

3. Low coercivity
➔ Soft magnetism

High-entropy alloys (HEAs)

1. Ferromagnetic element(ex. Fe, Co, Ni)
➔ are known to form HEAs

2. Topological distortion & chemical randomness
➔ Increases in electrical resistivity

3. Simple crystalline structure(ex. FCC)
➔ Geometric basis for reasonable malleability

2. Paper review –results

◈ Structure analysis

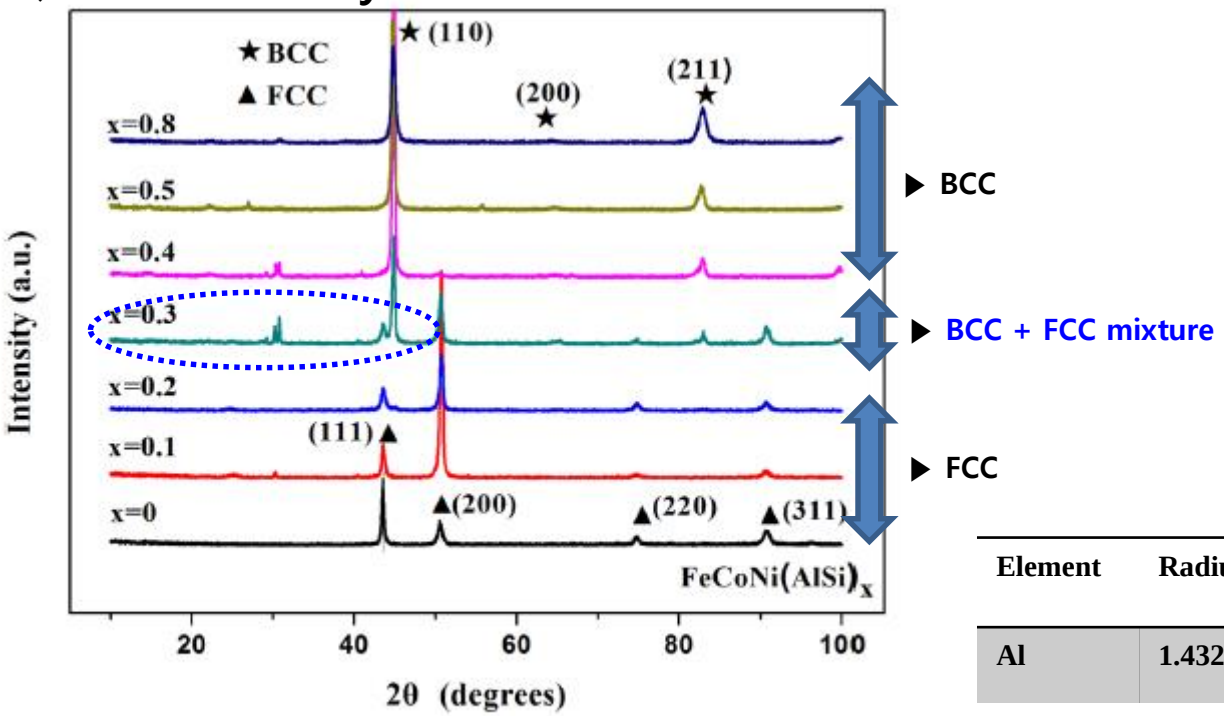
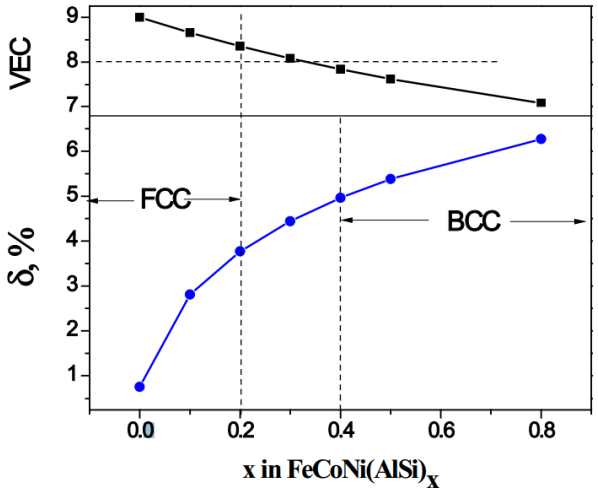


Figure 4 | XRD patterns of the as-cast $FeCoNi(AlSi)_x$ alloys.



Element	Radius(Å)	Pauling electronegativity	VEC
Al	1.432	1.61	3
Si	1.153	1.90	4
Fe	1.241	1.83	8
Co	1.251	1.88	9
Ni	1.246	1.91	10

▶ x ≤ 0.2 : single-phase FCC solid solution structure

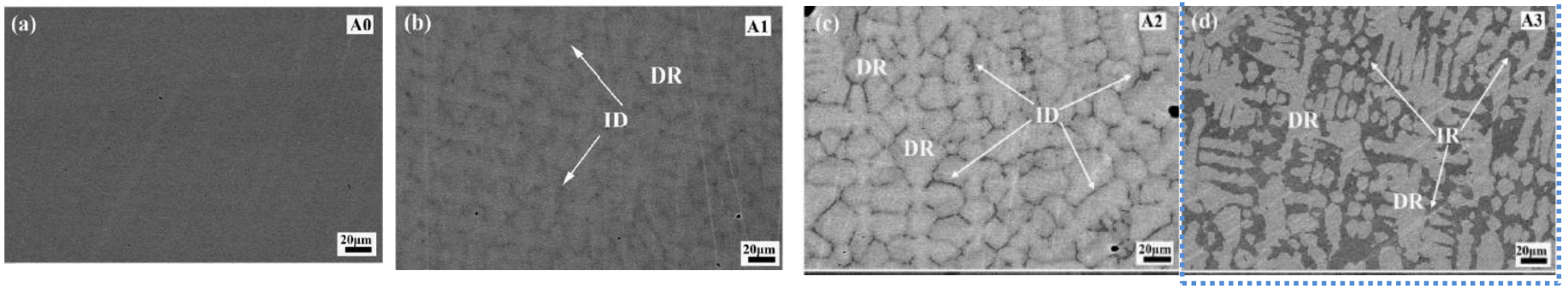
▶ x = 0.3 : BCC + FCC mixture structure

▶ x =0.4 : FCC → BCC transition

2. Paper review –results

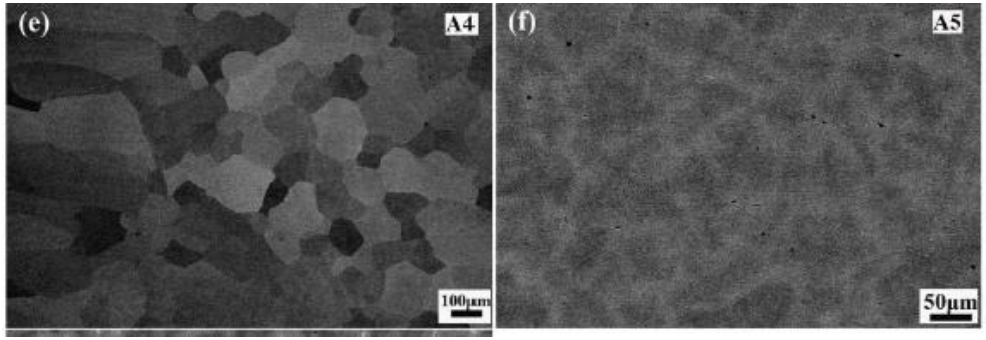
◈ Microstructure

▶ BCC + FCC mixture structure



▶ FCC structure

▶ The additions of Al and Si break the chemical homogeneity, and the dendritic **micro-segregation becomes increasingly prominent as x varies from 0 to 0.2**. The more Al and Si contents, the **more severe the segregation** is.

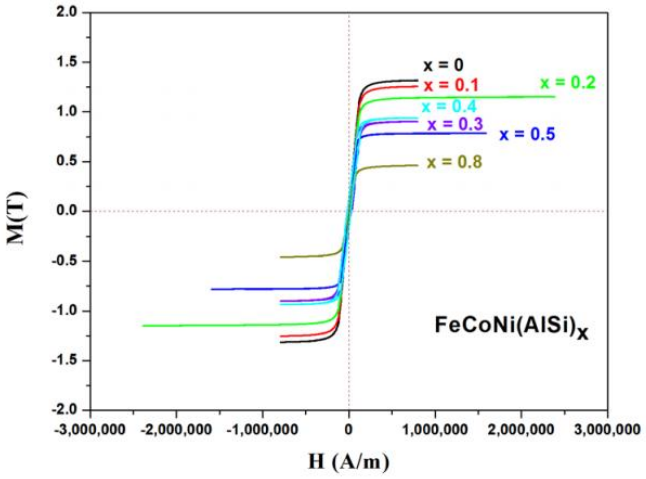


▶ BCC structure

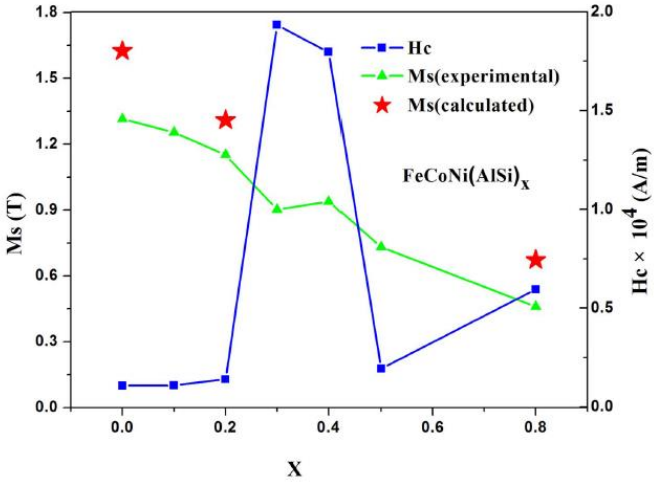
▶ In contrast, the **chemical heterogeneity in A4 and A5 alloys is less obvious**

2. Paper review –results

◈ Magnetic properties



	FeCoNi (FCC)	FeCoNi(AlSi)$_{0.2}$ (FCC)	FeCoNi(AlSi)$_{0.8}$ (BCC)	Al$_{0.2}$CrFeCoNi (FCC)	Al$_2$CrFeCoNi (BCC)
Exp. Ms (T)	1.315	1.151	0.460	n/a	0.106 [31]
Cal. Ms (T)	1.622	1.307	0.670	0.472	0.342
Fe (μ_B)	2.650	2.480	2.080	1.590	1.610
Co (μ_B)	1.660	1.500	0.880	0.760	0.550
Ni (μ_B)	0.620	0.520	0.210	0.170	0.092
Cr (μ_B)	-	-	-	- 0.700	- 0.120
Al (μ_B)	-	- 0.049	- 0.024	- 0.018	- 0.014
Si (μ_B)	-	- 0.058	- 0.030	-	-



- **Ms drops almost monotonically upon the additions of Al and Si**, from 1.315 T at x =0 all the way to 0.46 T at x=0.8
- **Hc appears rather irregular and unpredictable**:
  Hc is low at x=0.2, but increases dramatically at x=0.3

2. Paper review –results

◈ Electrical properties

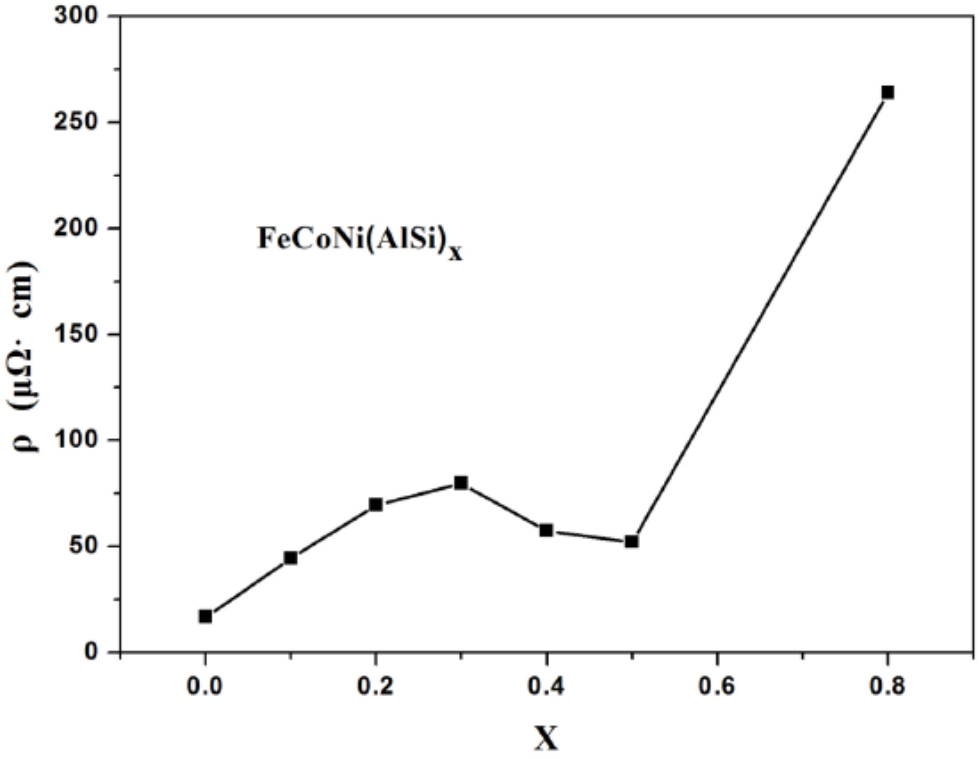


Figure 2 | The electrical resistivity (ρ) of $FeCoNi(AlSi)_x$ alloys obtained at room temperature.

Distorted lattice structure
→ Decrease electrical resistivity
→ Lattice scattering of electron

▶ **High electrical resistivity** is **an important requirement** for **SMMs used in the high-frequency magnetic field**, **as it reduces the eddy-current loss**. The typical electrical resistivity of the silicon steel is 50 ~ 80 Mv/cm.

3. Summary

Magnetic & Electric properties → changed by microstructural change

◈ Magnetic properties

▶ **Ms : FCC structure exhibit much higher saturation magnetization(Ms) than those with a BCC structure**

▶ **Hc(coercivity):** the various microstructures, together with the **lattice distortion** induced by Al & Si, will inevitably affect the magnetic domain-wall movement.

▶ **Hc :** This effect is the most obvious when x equals 0.3, at which **BCC and FCC phases coexist**, and the phase boundaries may greatly **hinder the domain-wall shift**, resulting in the highest coercivity.

◈ Electrical properties

▶ **Al** has a **larger atomic size** than other elements, and its addition may lead to **larger lattice distortion**. The distortion may **induce more electron scattering** and, thus, **reduce the mean free path, it may have contributed to the increased resistivity.**

▶ **Multi-phase solid solutions**, the **electrical resistivity** is also affected by **microstructure**, grain size, grain boundary, & texture. This feature may be responsible for the **deviation/fluctuation in the composition range** of $0.3 \leq x \leq 0.5$

Thank you