Soft magnetic metallic glass and nano-crystalline alloy.

2015.06.10 Kim Jeong soo

Contents

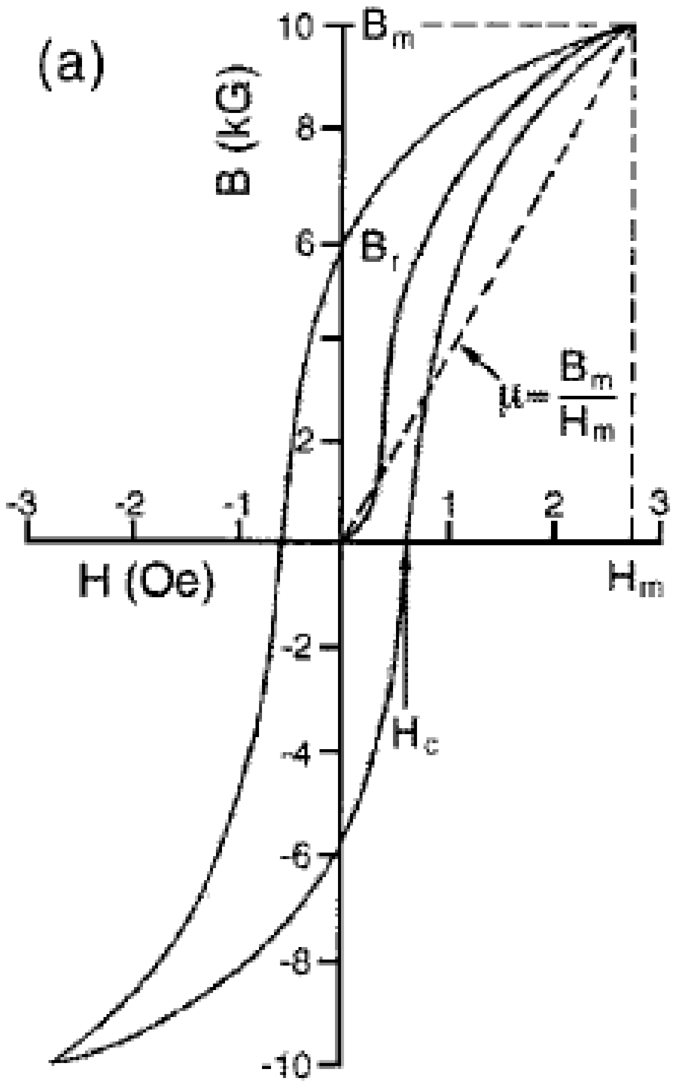
What is the condition for good soft magnetic materials?

1. **High permeability** : Permeability, $\mu = B/H = (1+\chi)$, is the material's parameter which describes the flux density, *B*, produced by a given applied field, *H*. In high permeability materials, we can produce very large changes in magnetic flux density in very small fields.

2. **Low hysteresis loss** : Hysteresis loss is the energy consumed in cycling a material between a field *H* and -*H* and then back again. The energy consumed in one cycle is $W_h = \oint M\,dB$ or the area inside the hysteresis loop. Also of concern at high frequencies are eddy current losses that are intimately related to the material's resistivity, ρ.

3. **Large saturation and remnant magnetizations** : A large saturation magnetization, M_s, and induction, B_s, is desirable in applications of soft magnetic materials.

4. **High Curie temperature** : The ability to use soft magnetic materials at elevated temperatures is intimately dependent on the Curie temperature or magnetic ordering temperature of the material.



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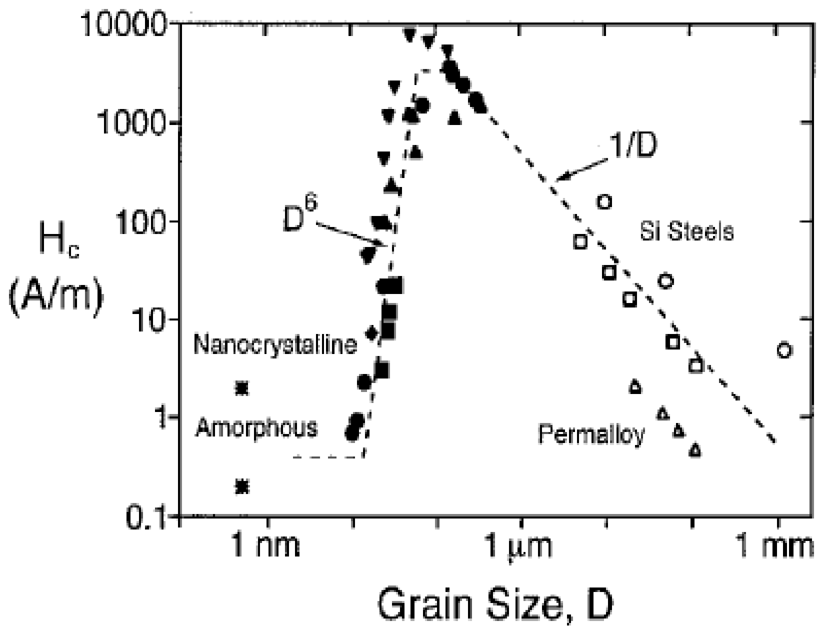


Conventional physical metallurgy

Optimizing the microstructure

Tailoring the chemistry

Grain size (D_g) > 0.1 – 1 μm

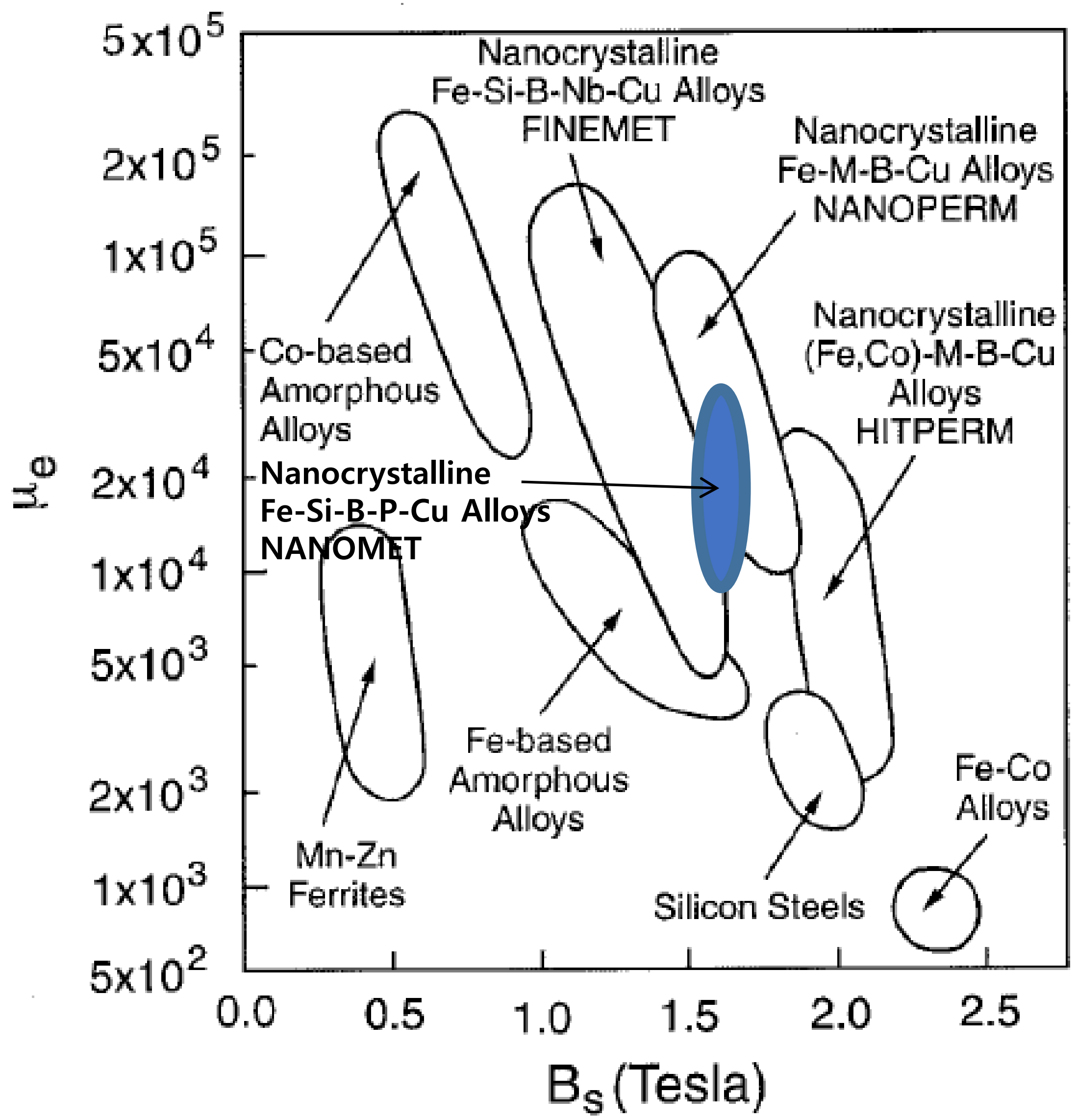
- **The magnetic hardness (the coercivity, H_c) is roughly inversely proportional to the grain size : $H_c \propto 1/D_g$**
- **The grain size exceeds the domain (Bloch) wall thickness (δ_W).**
- **Grain boundaries act as impediments to domain wall motion, and thus fine-grained materials are usually magnetically harder than large grain materials.**

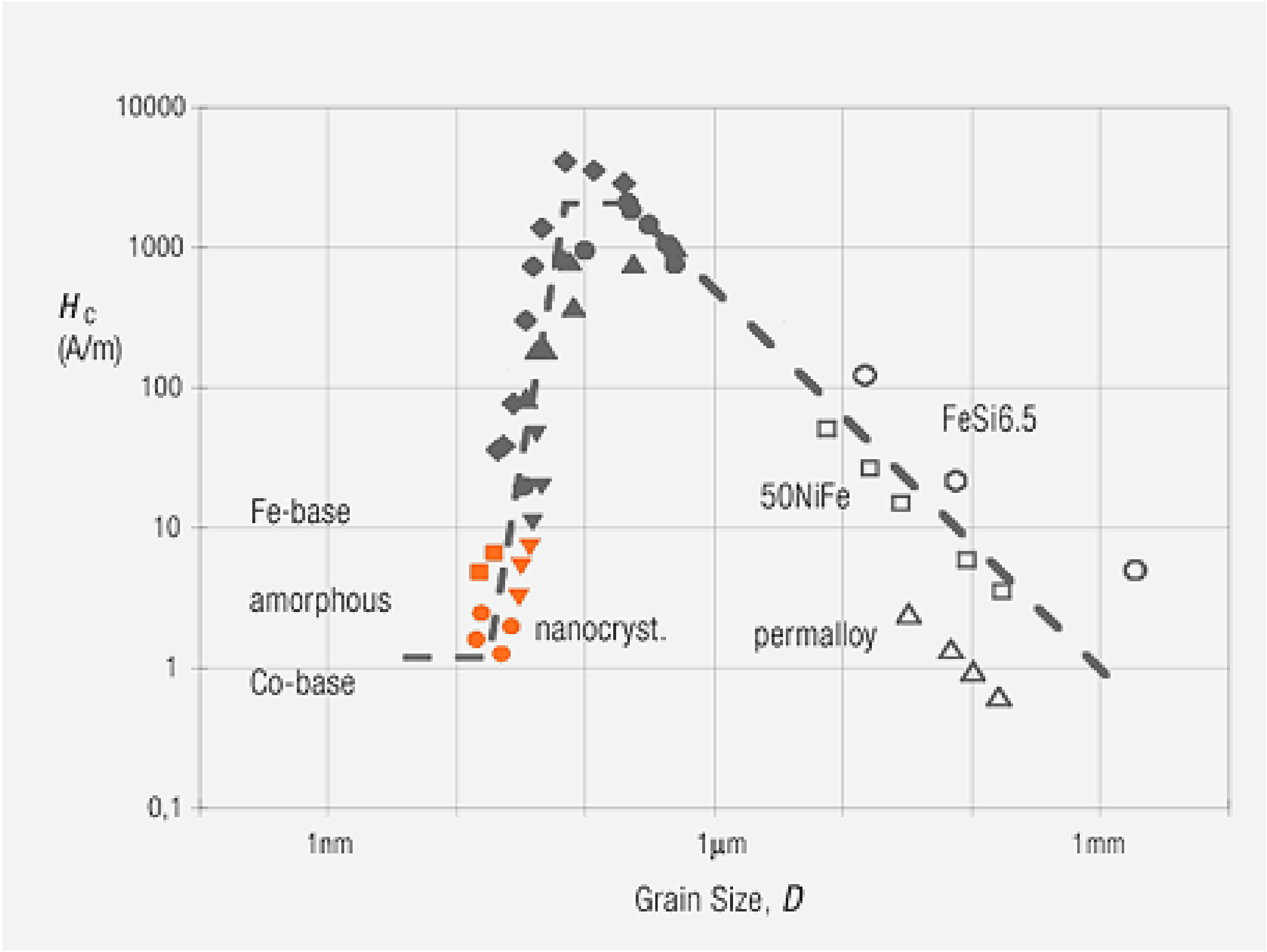
Grain size (D_g) < ~100 nm

- **H_c decreases rapidly with decreasing grain size : $H_c \propto {D_g}^6$**
- **The domain wall thickness (δ_W) exceeds the grain size.**
- **Fluctuations in magnetic anisotropy on the grain size length scale are irrelevant to domain wall pinning.**

Nanocrystalline and amorphous alloys have significant potential as soft magnetic materials.

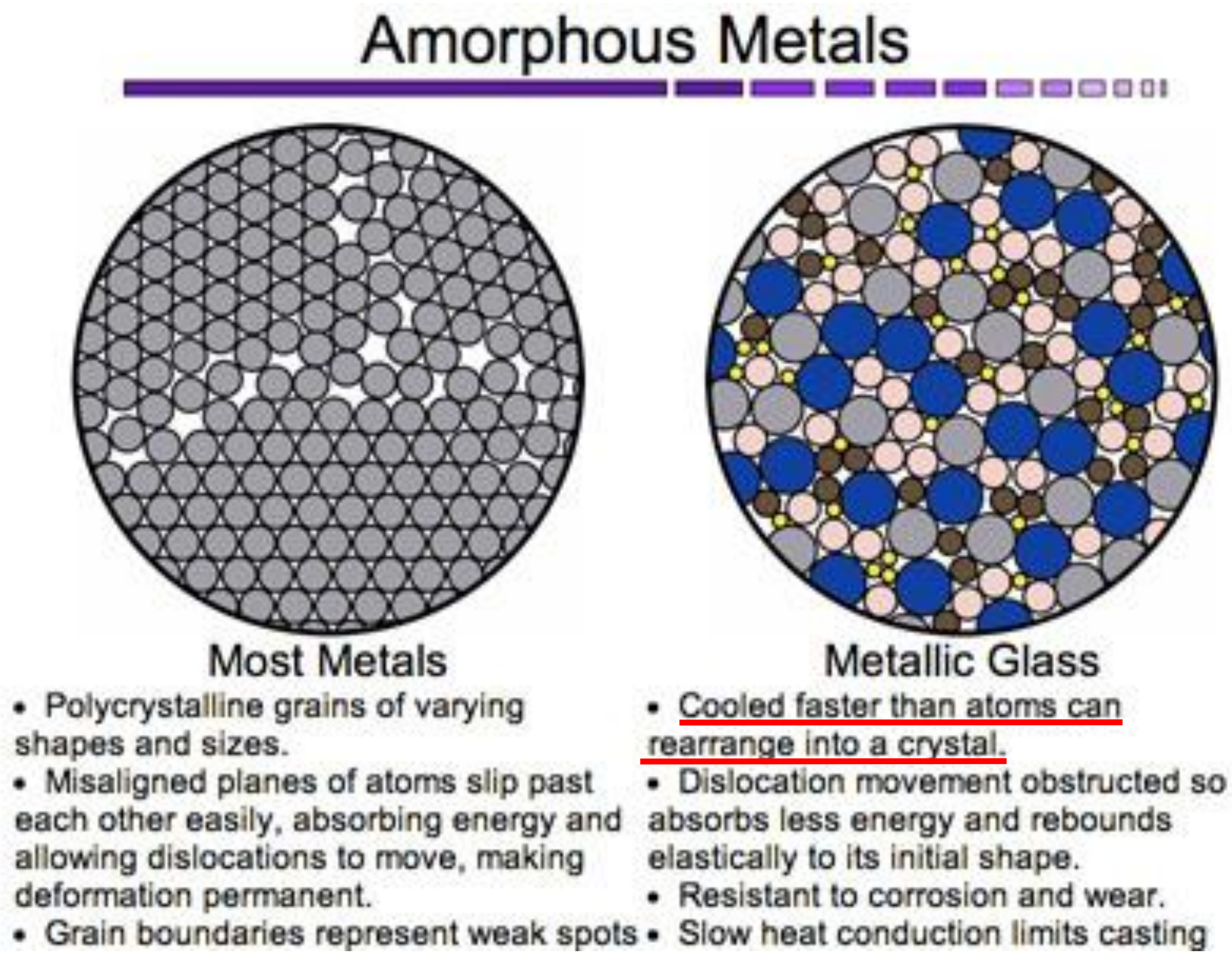
Nanocrystalline soft magnetic alloys





Then, How to make nanocrystalline alloys?

What is metallic glass?



Before making nanocrystal, we should get metallic glass.

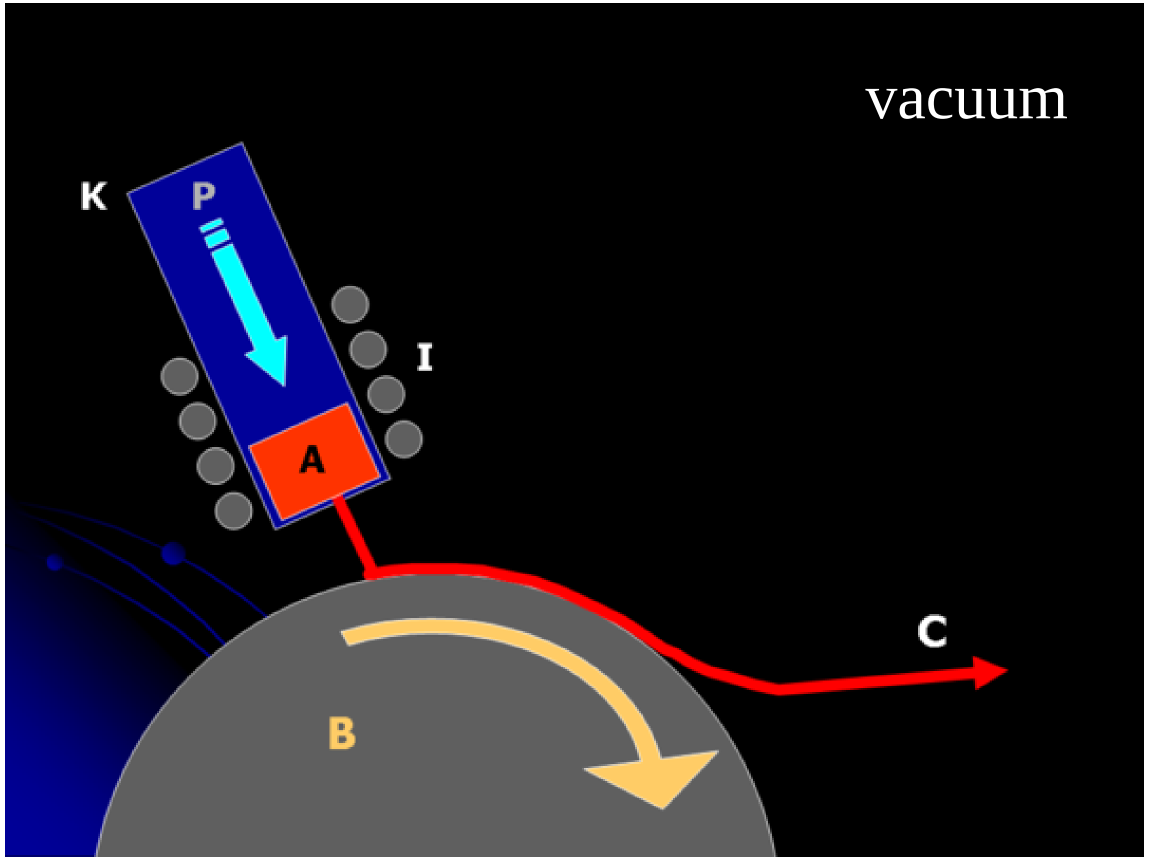
Metallic glass(also known as amorphous metal) is a solid metallic material with a disordered atomic-scale structure. Amorphous metals are non-crystalline and only have short range order.

These can be made by rapid quenching.

If these alloys are cooled faster than atoms can rearrange into a crystal, they cannot make crystal.

How to make metallic glass

Melt spinning : technique used for rapid cooling of liquids.



- A thin stream of liquid is dripped onto the rotating wheel, causing rapid solidification.
- The cooling rates achievable by melt-spinning are on extremely high cooling rate.

After making metallic glass,

it should be annealed to get fine nanocrystal.

#1_Effect of P on crystallization behavior and soft-magnetic properties of $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ nanocrystalline soft-magnetic alloys (2011)_ Inoue group (Thin Solid Films 519 (2011) 8283–8286)

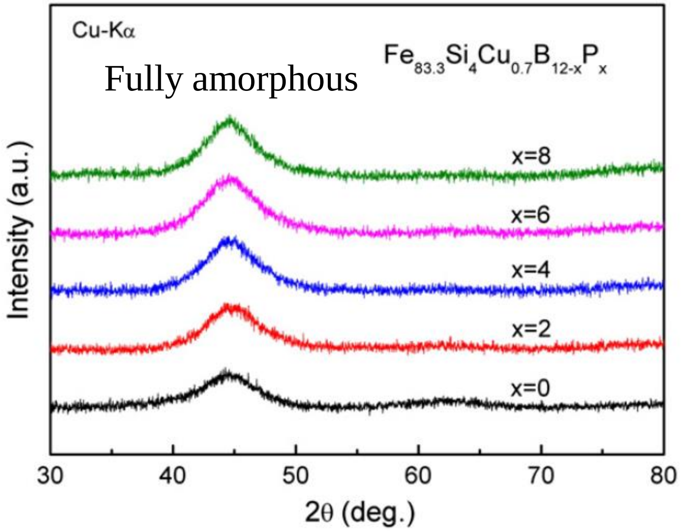


Fig. 1. XRD patterns of the $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ (x = 0–8) melt-spun ribbons.

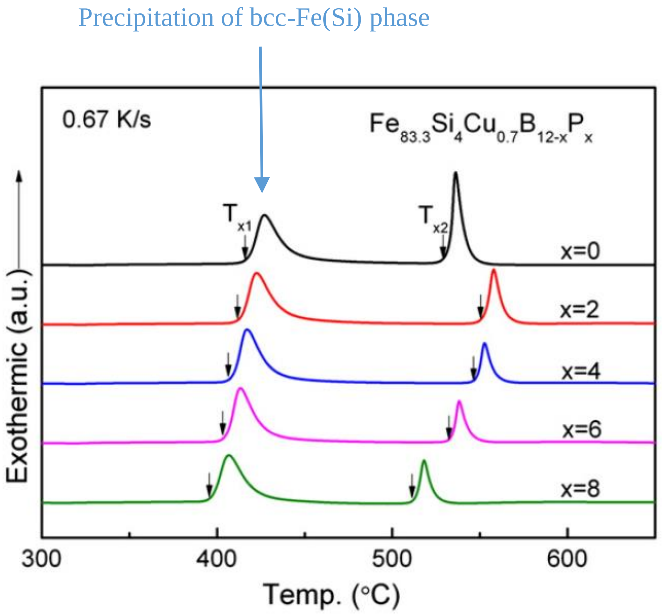


Fig. 2. DSC curves of $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ (x = 0–8) melt-spun ribbons measured at a heat rate of 0.67 K/s.

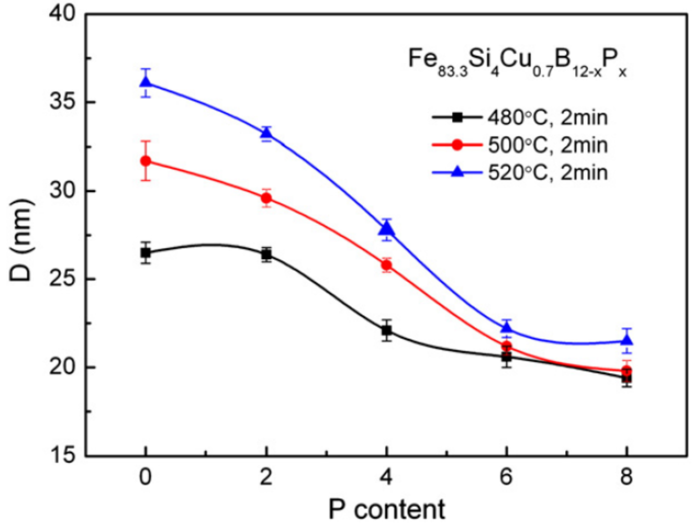


Fig. 4. Dependence of bcc-Fe grain size on the P content of $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ (x = 0–8) alloy ribbons annealed at 480, 500 and 520 °C for 2 min.

- P addition is very effective in widening the optimum annealing temperature range and refining of bcc-Fe grain size in addition to the increasing of nanocrystalline grain density.

- P addition ↑ → grain size ↓

since B and P hardly solidifies in the bcc-Fe(Si) phase, the replacement of B by P in the amorphous matrix increases with increasing number of nanocrystalline grains. This suggests that the grain growth is suppressed by the increase of P content in the amorphous matrix phase.

It is known that the precipitation of bcc-Fe(Si) is triggered by the Cu-enriched clusters precipitated during annealing process and/or the primary crystals in the as-quenched state.

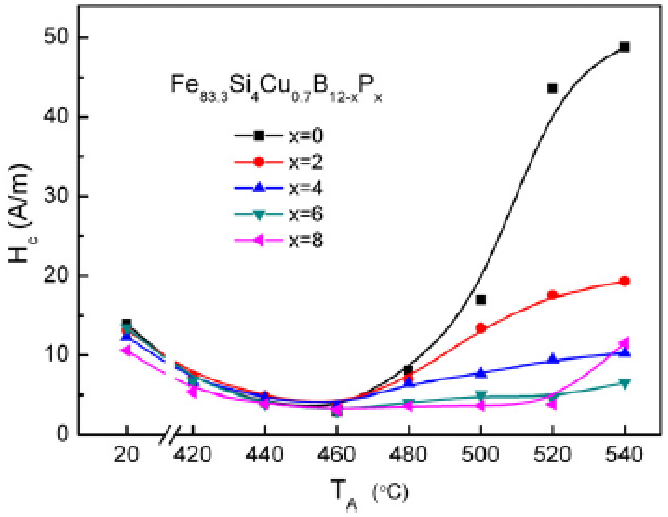


Fig. 3. Annealing temperature (T_A) dependence of H_c for the $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ (x = 0–8) ribbons annealed for 2 min.

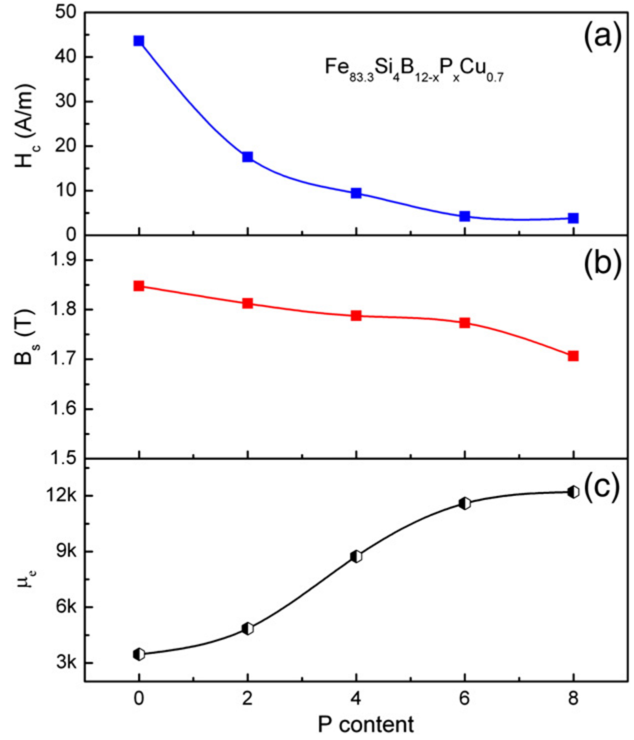


Fig. 5. The changes of (a) coercive force (H_c), (b) saturate magnetization (B_s) and permeability (μ_e) as a function of P content for the $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ (x = 0–8) nanocrystalline ribbons annealed at 520 °C for 2 min.

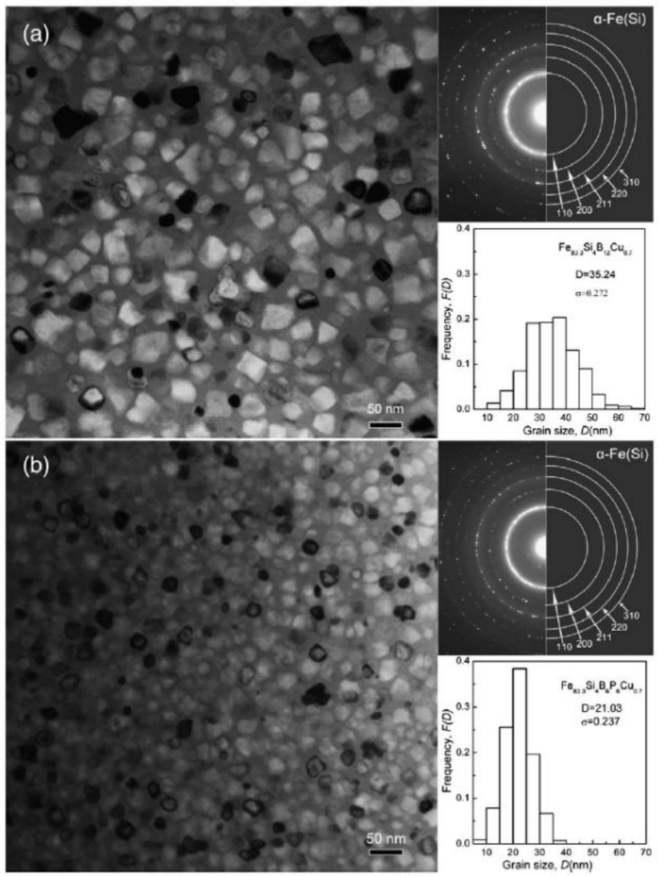


Fig. 6. TEM bright field images, selected area electron diffraction (SAED) patterns and grain size distribution of melt-spun $Fe_{83.3}Si_4B_{12-x}P_xCu_{0.7}$ alloy ribbons annealed at 520 °C for 2 min (a) x = 0 and (b) x = 6.

The coercivity Hc markedly decreases with increasing x and exhibits a minimum at around x=6–8, while the saturation magnetic flux density Bs shows a slight decrease.

5. Conclusion

In conclusion, the effect of P addition on the soft-magnetic properties, crystallization behavior and microstructure of high Fe content soft-magnetic nanocrystalline $Fe_{83.3}Si_4Cu_{0.7}B_{12-x}P_x$ (x = 0 to 8) were investigated. As a result, H_c decreases and μ_e increases markedly with increasing P content, accompanied with significant reduction crystalline grain size. Excellent magnetic properties such as a low H_c of about 4.2 A/m and a high B_s of 1.77 T were obtained in the alloy with x = 6. In the present alloy system, more than 6% P addition favor nucleation of primary crystals in high number density.

reference

- http://nation.towergaming.com/wp-content/uploads/2010/05/glass.jpg
- Thin Solid Films 519 (2011) 8283–8286
- Wikipedia

Thank you for listening