3D atomic-scale insights into the substantial coercivity enhancement of Sm(CoFeCuZr)z permanent magnets with Cu powder doping

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Research interest in the 2:17 type Sm-Co permanent magnets with excellent thermal stability and high intrinsic coercivity has been revived recently due to the increasing demand for high-temperature applications [1]. In order to achieve high magnetic energy product simultaneously, increasing the concentration of Fe in the magnet has been considered as an efficient approach. However, this degrades the intrinsic coercivity and squareness of demagnetization curve unavoidably. Up to now, numerous investigations show that the addition of Cu in the $SmCo_5$ cell boundary phase increases the domain wall pinning force, resulting in the high coercivity of the magnet. However, Cu-lean zone was still observed at the grain boundary (GB) phase of the 2:17 type $Sm(CoFeCuZr)_z$ magnets, obstructing the further coercivity enhancement [2]. Recently, a technique via Cu powder addition was proposed by M. Yue's group. Substantial coercivity enhancement in $Sm(Co_{0.665}Fe_{0.25}Cu_{0.06}Zr_{0.025})_7$ permanent magnets from 950 to 1688 kA/m has been achieved with 1 wt.% Cu powder doping. However, the underlying mechanism is not well understood. Hence the aim of this work is to characterize the chemistry of cell boundary phase near the Cu-rich zone by correlating electron backscatter diffraction (EBSD), energy dispersive X-ray spectroscopy (EDS) and the-art-of-state 3D atom probe tomography (APT) for a better controllable fabrication protocols.

The EBSD and EDS results indicate the enrichment of Cu near the GB phase, which is believed due to the Cu powder doping. The APT results indicate a transition zone near the GB phase from the Cu-lean zone to Cu-rich zone. The local concentration of Cu in the cell boundary zone increases from ~17.0 at.% in the Cu-lean zone to ~25.0 at.% in the Cu-rich zone (shown in Figure 1), indicating that the high concentration of Cu in the Cu-rich zone results in a large domain wall energy difference between 2:17 phase and 1:5 cell boundary phase, giving rise to strong pinning. In detail, the local composition of Cu reduces from ~17.0 at.% far from the GB phase to ~6.0 at.% near the GB phase in the Cu-lean zone. The local composition of Cu increases from ~20.0 at.% near the GB phase to ~25.0 at.% far from the GB phase in the Cu-rich zone. In addition, Zr-rich phase is not likely to form near the GB phase. The coercivity mechanism of the $Sm(Co_{0.665}Fe_{0.25}Cu_{0.06}Zr_{0.025})$ permanent magnets with 1 wt.% Cu powder doping is thoroughly discussed based on these new findings.

References:

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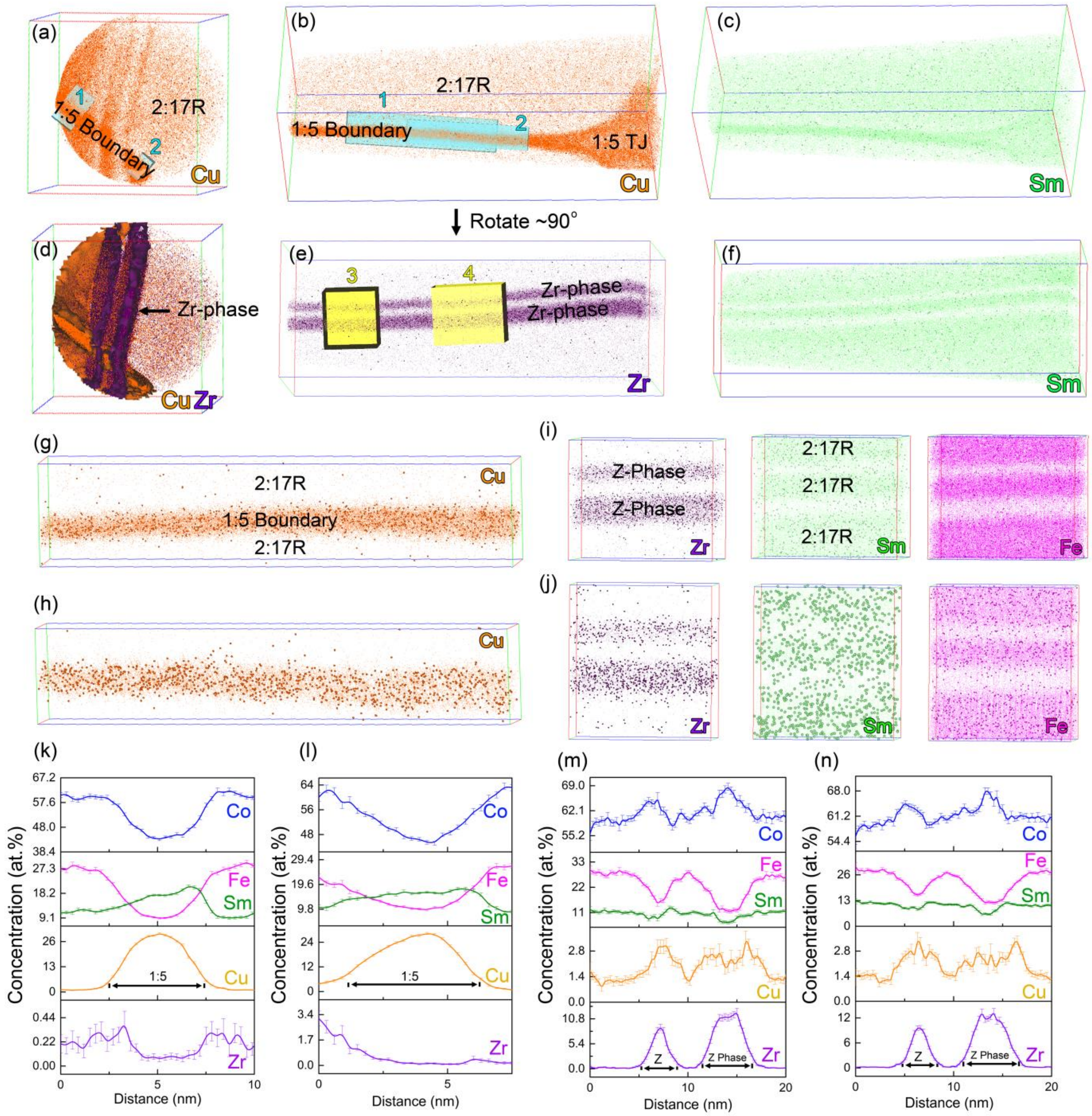

Figure 1. 3D reconstruction of atoms from the Cu-rich region . 3D atom distribution map of (a) Cu (top view), (b) Cu (side view), (c) Sm (side view) of the tip. (d) Iso-concentration surfaces of Cu (12.0 at.%) and Zr (5.9 at.%). 3D atom distribution map of (e) Zr (side view) and (f) Sm (side view). (~150×55×55 nm^3). 3D atom distribution map of Cu in the (g) box 1 (~60×7×13 nm^3) and (h) box 2 (~49×4×9 nm^3). 3D atom distribution map of Zr, Sm, and Fe in the (i) box 3 (~15×21×23 nm^3) and (j) box 4 (~15×15×20 nm^3). (k), (l), (m) and (n) are 1D composition profiles of (g), (h), (i) and (j).