Magnetic Studies of Properties of Ni-based Substrates and Coated Conductors

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Objectives

- Determine basic ferromagnetic properties of Ni-based alloys for substrates
- Establish level of FM (hysteretic) loss *W*, for potential ac applications
- Magnetically characterize coated conductor on Cu / Ni-coated substrate

Materials

- Biaxially textured $Ni_{1-x}W_x$ alloys with x = 0, 3, 5, and 9 at %.
- Substrate materials from AmSC, Oxford, ORNL; CC from ORNL

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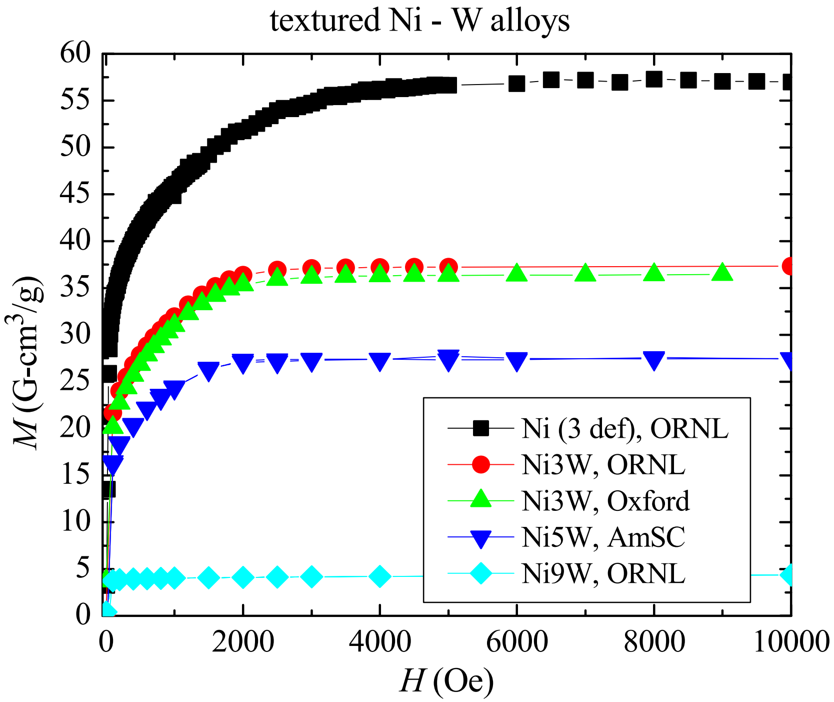
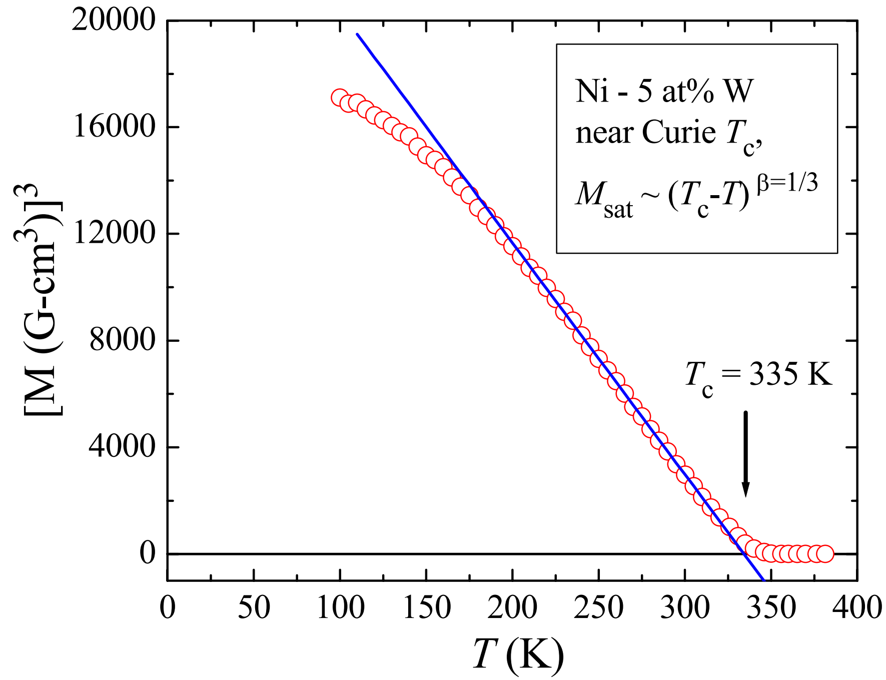
Analogies between Superconductors and Ferromagnets

Superconductor	Ferromagnet
Intrinsic properties	
Transition temperature T_c	Curie temperature T_c
Condensation energy,	Condensation energy,
Thermodynamic critical field	Spontaneous magnetization
...	…
Extrinsic properties	
Vortex pinning,	Domain wall pinning,
Critical current density	Coercive field, coercivity

Studies were conducted in a SQUID magnetometer, with dc and ac fields applied || plane of Ni-W foil samples, to minimize demagnetizing effects.

Determination of M_{sat} and Curie T_c : $M \propto (T_c - T)^{1/3}$

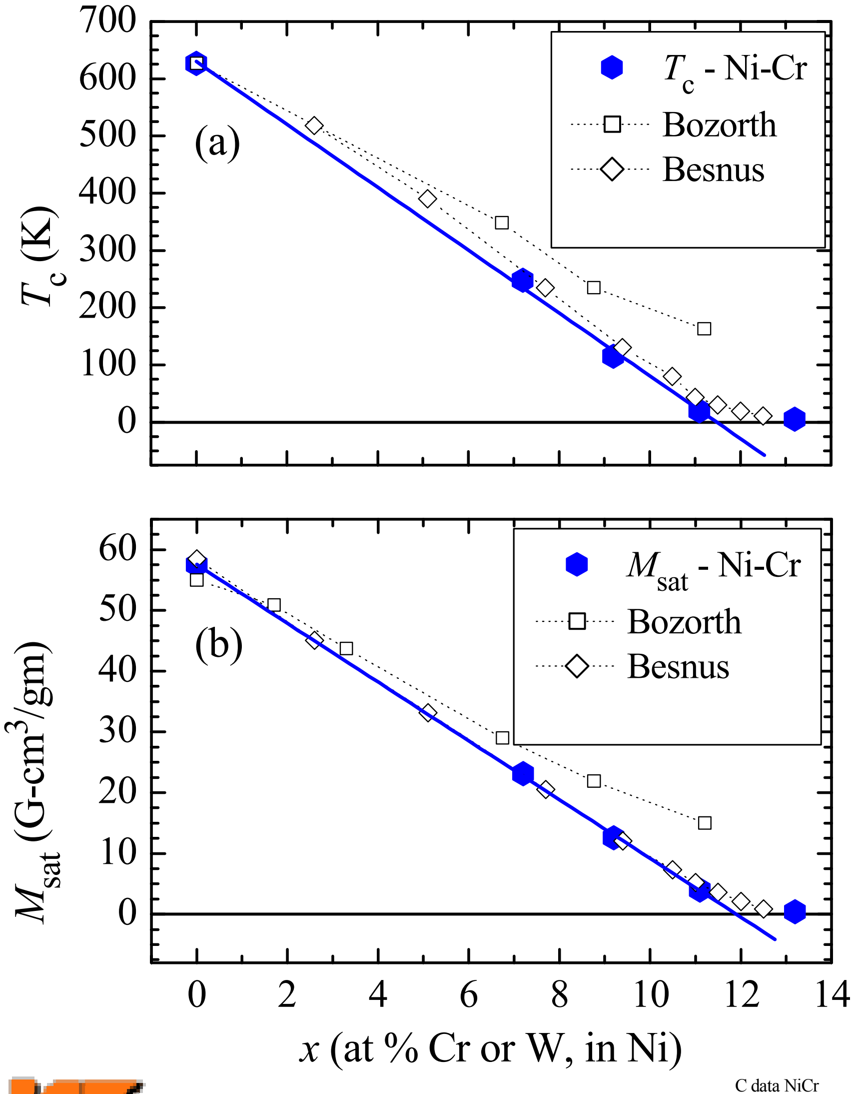




NiW SummaryandTables

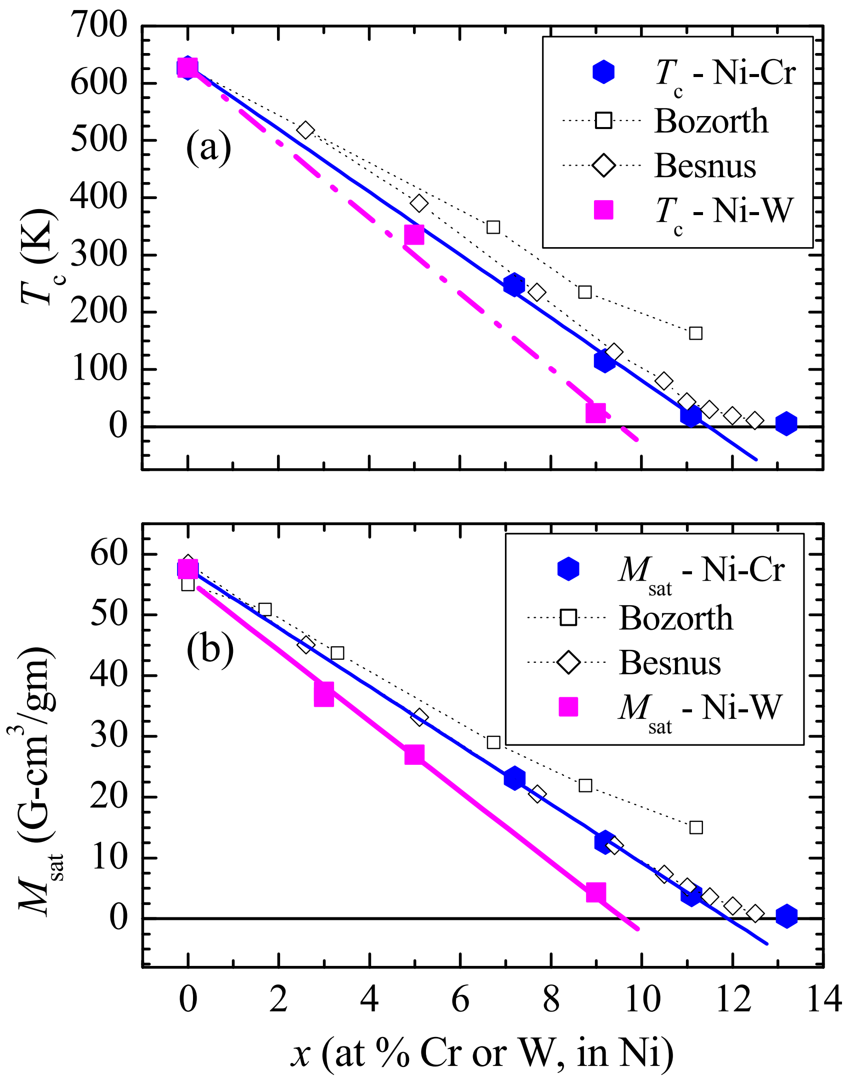
For Ni, magnetocrystalline anisotropy gives [111] easy axis;
Biaxial texturing and sample geometry has field $H \parallel [100]$
$\Rightarrow$ rounding of magnetization curves $M(H)$.

Dependence of Curie T_c and M_{sat} on Cr-content x



- Our previous work - Ni-Cr (Physica C **370**, 169 (2002)
- *Ferromagnetism,* R. P. Bozorth (IEEE Press, 1978)
- Besnus, Gottehrer, and Munshy, Phys. Stat. Sol. B **49**, 597 (1972).

Dependence of Curie T_c and M_{sat} on W-content x



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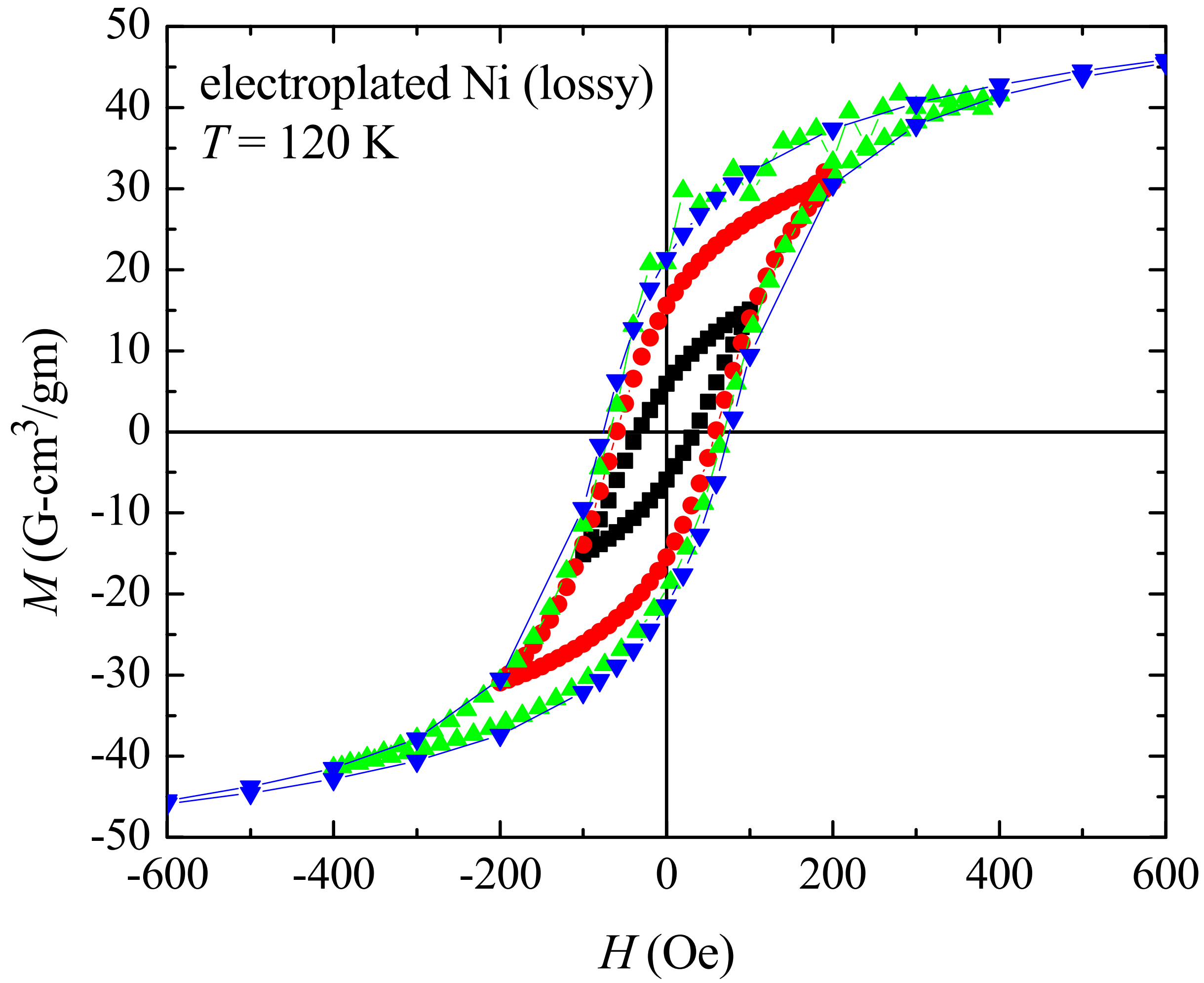
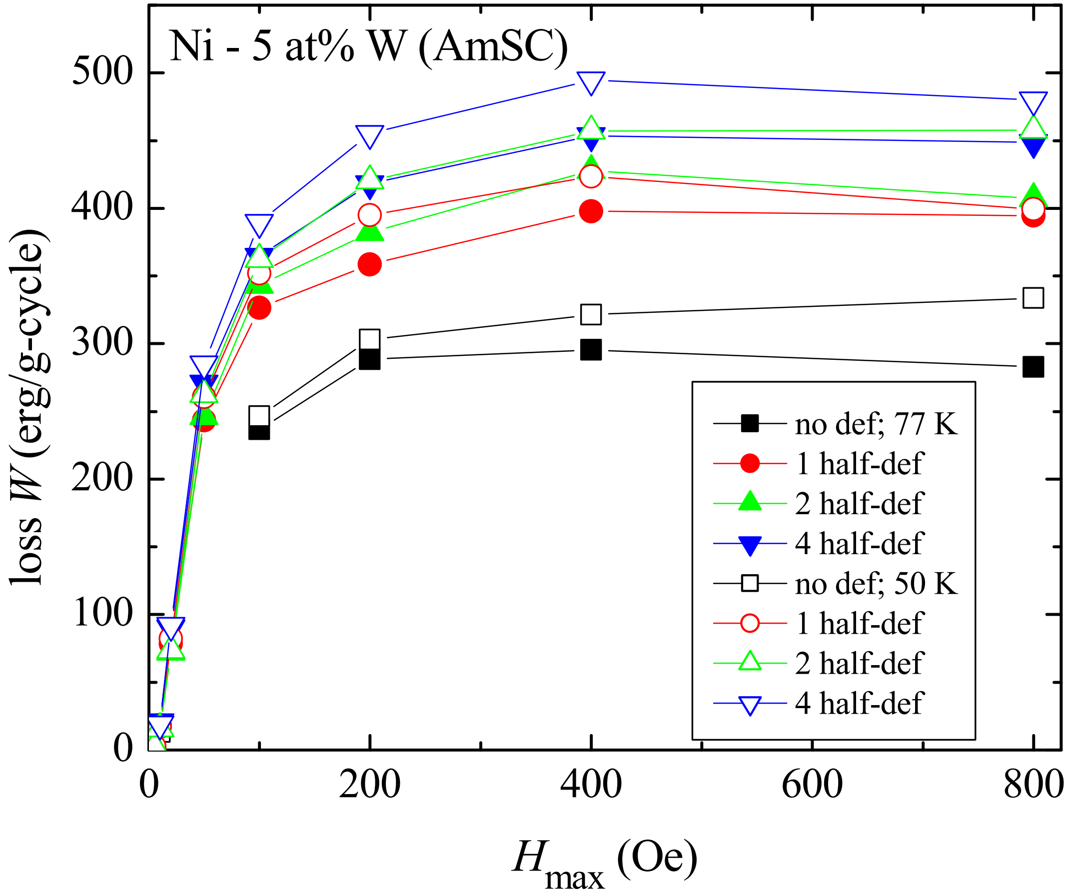
- Present work on Ni-W

Obtain FM loss from $M(H)$ loop area



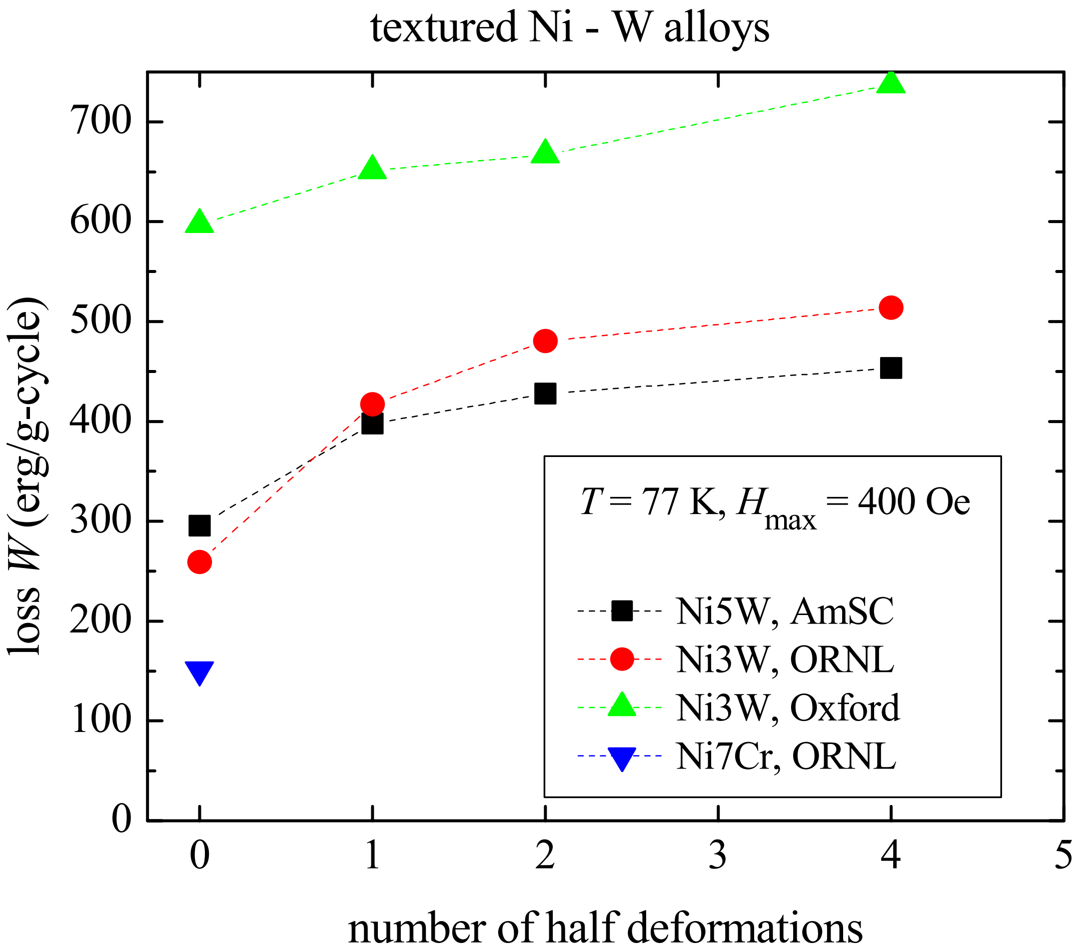
FM loss $W = \oint M \mathrm{d}H$ = loop area, which increases with H_{max}

FM loss W vs H_{max} at 50, 77 K, with bending deformation



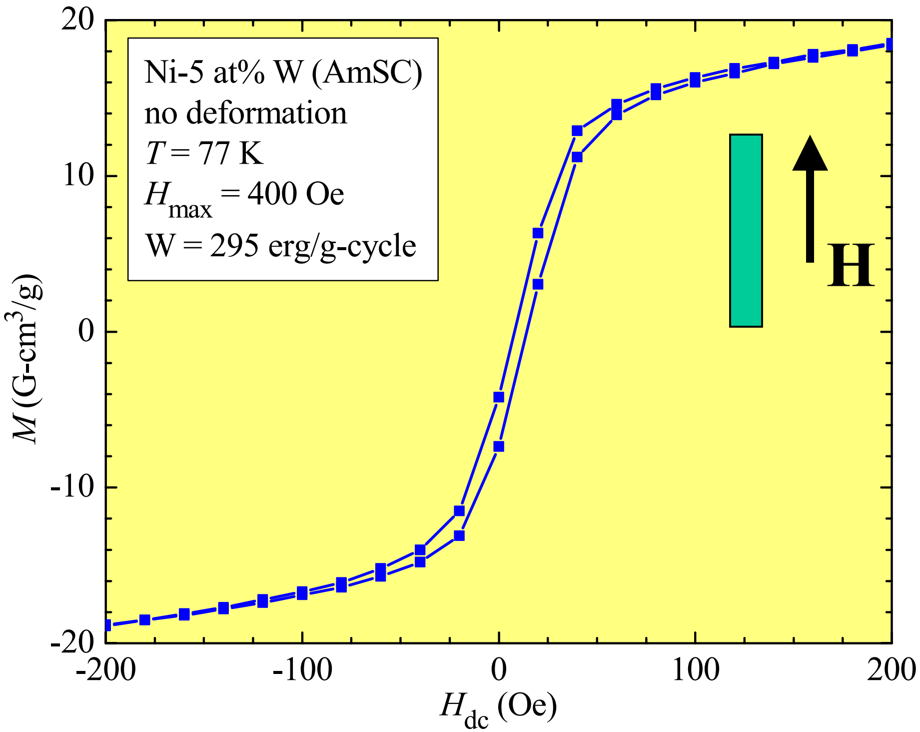
- Loss W first increases ~ linearly with H_{max}, then saturates;
- loss increases with # cycles of deformation (0.4% bending strain);
- loss increases somewhat as T decreases.

FM loss *W* vs damage due to # of bending deformations



one half-deformation: | ⇒ {⇒ | ; second half-deformation | ⇒ }⇒ |

Illustration: relative losses for YBCO / Ni-5 W



- HTSC and FM power losses scale very differently with current I_0/I_c

- HTSC loss can be reduced (ideally) by factor of $1/N$ by subdividing tape into N (non-interacting) conductors.

Loss in HTSC (8 mm × 2.5 μm):
for $J_c = 1\times10^6$ A/cm^2, I_c = 200 A

If $I_0 = I_c$, Norris gives ac loss/m of
$L_{c,\,max} = (\mu_0/2\pi)\, I_c^2$ = 8 mJ/m-cycle
⇔ power = **2400 mW/(kA-m)**

For $I_0 = I_c/2$ = 100 A,
$L_c \approx (1/17)\, L_{c,\,max}$ = 0.46 mJ/m-cycle
⇔ power loss = **270 mW/(kA-m)**

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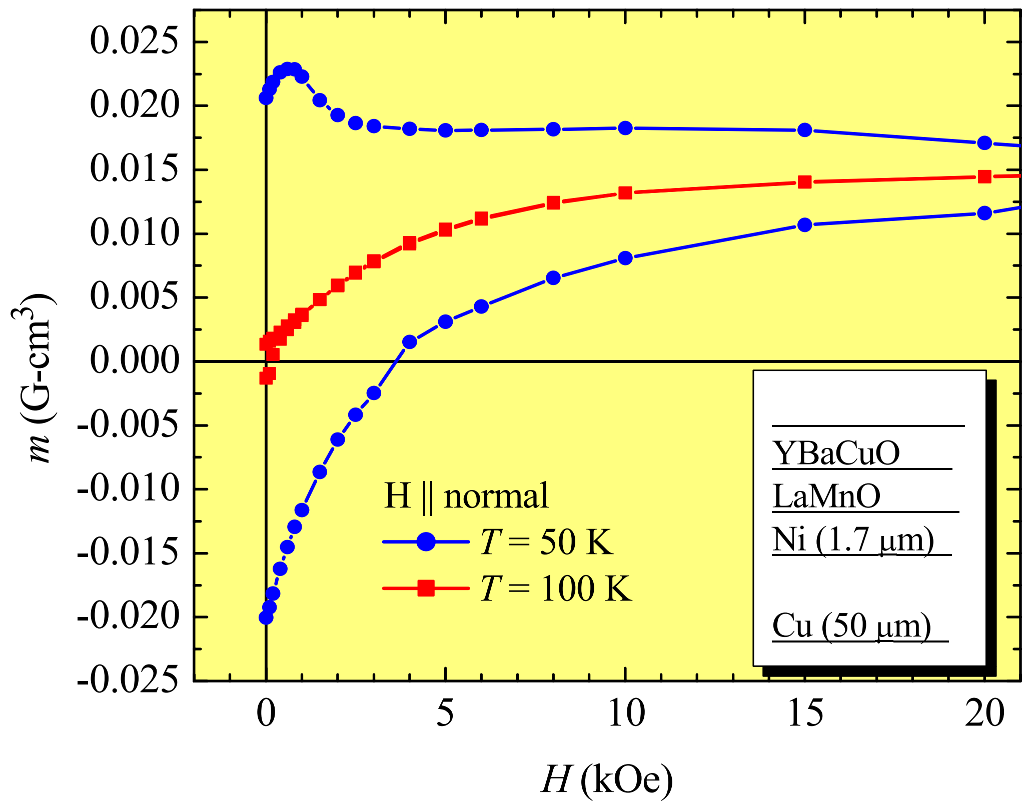
Substrate Loss (8 mm × 50 μm):
0.4 cm^3 of alloy/m × 0.27 mJ/cm^3 ⇒

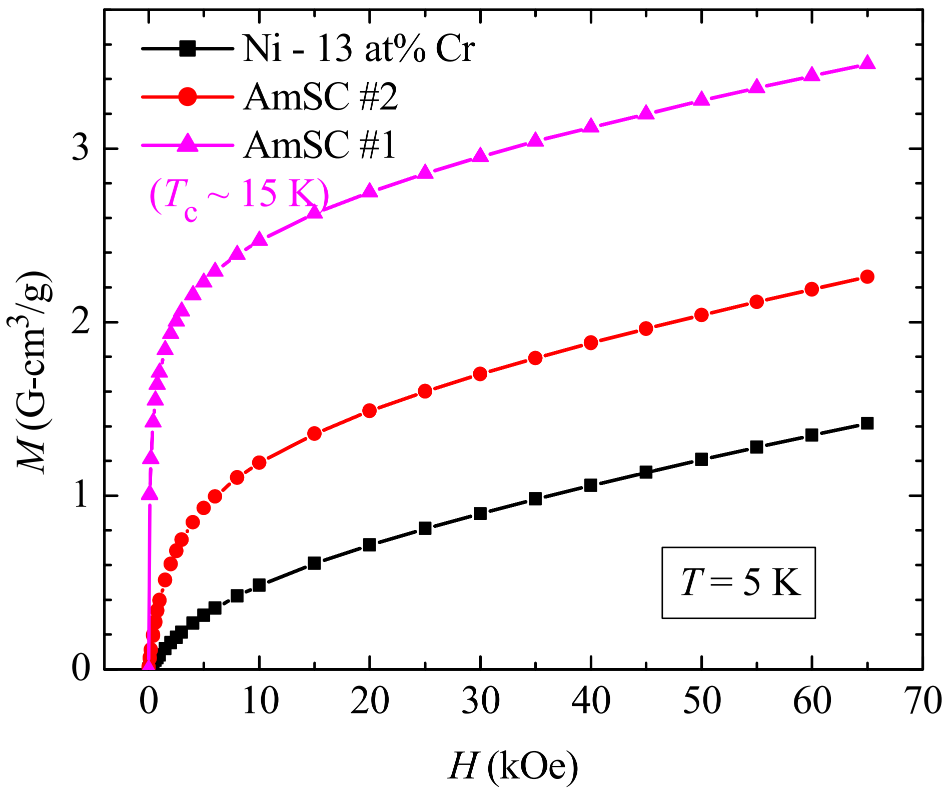
$L_{c,\,FM}$ = 0.10 mJ/m-cycle (Ni-5%W)
(and 0.7mJ/m-cycle for pure Ni)
⇔ power loss = **64 mW/(kA-m)**
(and 430 mW/kA-m for pure Ni)

M(H) for coated conductor YBCO/LMO/Ni/Cu



T. Aytug et al., (J. Mater. Res. Rapid Comm., in press)
J_c (H ~ 0) = 1.2 MA/cm^2 @ 50 K; 0.25 MA/cm^2 @ 77 K
max FM power loss ~ 2/3 of example with Ni - 5 at % W.

Other Ni alloys have minimal/no FM & biaxial texture



Magnetization *M* is much smaller than for more concentrated alloys.

For these Ni-based alloys, the FM vanishes at temperatures of potential applications.

Conclusions

- $Ni_{1-x}W_x$ alloys with $x = 0, 3, 5,$ and 9 at % W: M_{sat} (and ~T_c) decrease linearly with x; critical concentration $x_c \approx 9._5$ at. % W.

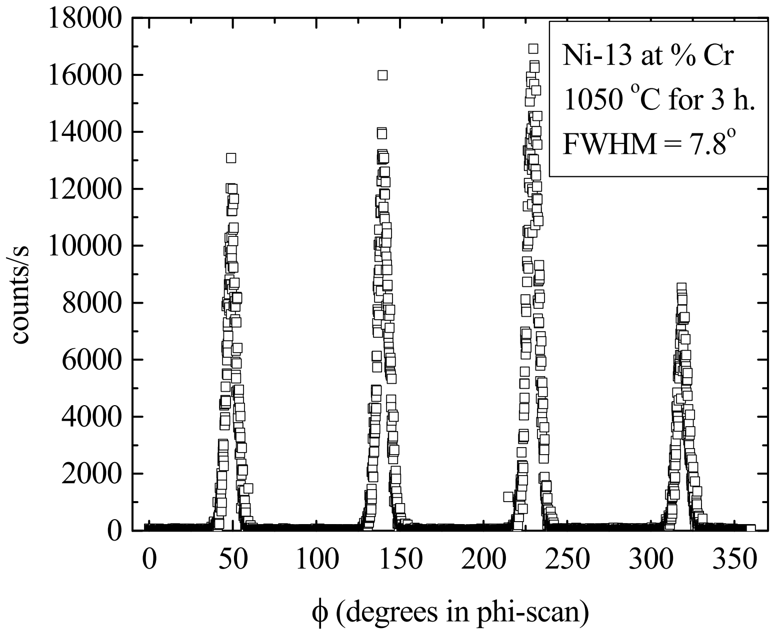
- FM hysteretic loss W ~ 300-600 erg/g-cycle in biaxially textured alloys with tungsten contents of 5-3 at. %

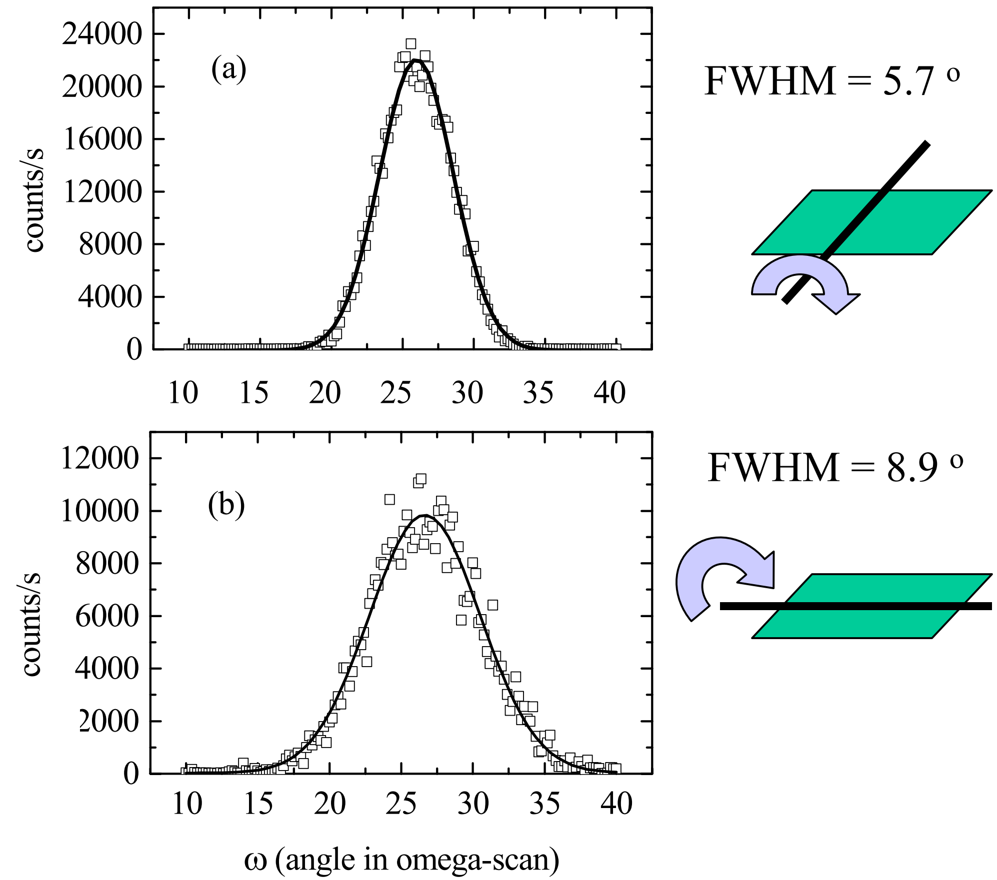
- Loss W increases at first ~ linearly with field excursion H_{max}, then saturates at larger H_{max}

- Loss W increases with bending deformation (0.4 % bend strain) ⇔ pinning of domain walls by induced defects.

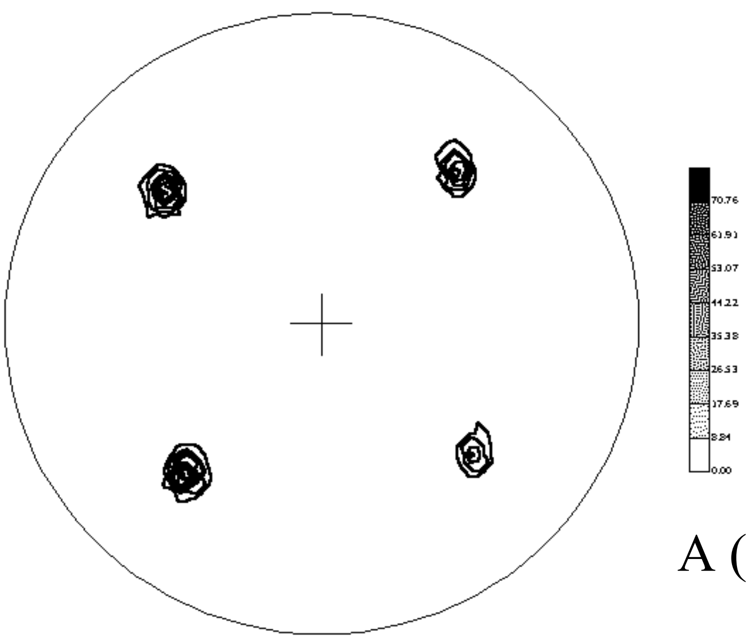
- FM loss independent of ac frequency; stable with T-cycles; decreases drastically when alloy is saturated by dc bias field.

Biaxial Texture Ni-Cr





ω-scans for out-of-plane texturing



A (111) pole figure