$L1_0$-ordered FePtAg-C granular thin films
for thermally-assisted magnetic recording media

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Goal of Project: FePt HAMR media > 4 Tbits/in²

Requirement: High $K_u (>10^7\text{erg/cc})$ - $L1_0$-ordered FePt thin film $D\sim4\text{nm}$ with uniform size distribution (001) alignment on commercially viable substrates

Our previous work: FePtAg-C granular film

Degree of $L1_0$ Order: 0.99
Grain size: 6.1±1.8nm
Center to center: 9.6nm
C spacing: 3.5nm
Thickness: 6.4nm
Ra: 0.45 nm, PV: 5.84 nm

$H_k \approx 65\text{ kOe}$
$H_{C,\text{perp}} = 37\text{kOe}$
$H_{C,\text{inp}} = 5\text{kOe}$
$K_u = 4.2\times10^7\text{erg/cc}$
$M_s = 740\text{ emu/cc}$
$E_b = 7.6\text{eV}$
$K_u V/k_BT = 300$
$H_{C0} = 43.6\text{kOe}$
$\Delta H_c/H_c = 0.27$
Optimized FePtAg-C Granular Film

(001) alignment is excellent
$S = 0.90$

$H_C = 35\text{kOe}$, $K_u = 4.3\times10^7\text{erg/cc}$
There is no one to one correspondence between the FePt particles and MgO grains.
Energy filtered TEM images

Zero-loss

50 nm

Fe

Pt

Ag
Energy filtered TEM images

Zero-loss

- Ag is dissolved in FePt grains.
- C falls outside FePt grains, as spacer.
Temperature dependence of remanence ($M_r$)

- Low temperature measurement also supported small $J$ value of 0.5.
- $T_c$ was estimated to be 460-480°C.

H. Nemoto and I. Takekuma, Hitachi
TAR static tester results

92 nm track width

81 nm track width

81nm track x 15nm bit ~ 530 Gb/in².
Optimized FePtAg-C film

Degree of $L_1$ Order: 0.90
Grain size: 6.2±1.4nm
Center to center: 9.6nm
C spacing: 3.5nm
Thickness: 6.4nm

$H_k \approx 65 \text{kOe}$
$H_{C,\text{perp}} = 35\text{kOe}$
$H_{C,\text{inp}} = 7\text{kOe}$
$K_u = 4.3 \times 10^7 \text{erg/cc}$
$M_s = 740 \text{emu/cc}$
$E_b = 5.1 \text{eV}$
$K_u V/k_B T = 200$
$H_{c0} = 37.5 \text{kOe}$
$T_c = 460-480\text{C}$
Future project directions recommended by ASTC

1. Well segregated and uniform single-column grains selection of the matrix

2. Reduce the process temperature: for NiP/Al substrate addition of the forth element

3. ECC and HAMR

4. Origin of the in-plane hysteresis loop.

5. Use single composite target.
FePt-SiO$_2$ granular films

FePt(4,6)-SiO$_2$

MgO (10)

Oxidized Si. Substrate

FePt(4nm)-50% SiO$_2$

FePt(6nm)-50% SiO$_2$

T$_s$ = 500$^\circ$C

Intensity (a.u.)

2$\theta$ (degree)

M (emu/cc)

H (kOe)

Intensity (a.u.)

2$\theta$ (degree)

50 nm

20 nm

FePt(4,6)-SiO$_2$

MgO (10)

Oxidized Si. Substrate

FePt(4nm)-50% SiO$_2$

FePt(6nm)-50% SiO$_2$

early optimized FePtAgC

Intensity (a.u.)

2$\theta$ (degree)
Other spacer material: FePt-B

Film: Oxi.Si. / MgO(10) / FePt(4)-Bx% @ 450°C
Rate of FePt 0.013nm/sec, \( P_{Ar} = 0.6 \text{Pa} \)

- FePt(4)-Bx%
- MgO (10)
- Oxidized Si.
- Substrate

FePt-B40% (5.6nm)
FePtX-C films ($x = \text{Ag, Cu}$)

Fe$_{49}$Pt$_{41}$-$X$$_{10}$-50%C

- Cu10%
- Au10%
- Ag10%
- early optimized FePtAgC

Intensity (a.u.)

2θ (degree)

FePtX-C50% (6)

MgO (10)

Oxidized Si. Substrate
FePtX-C films ($x = \text{Ag, Cu}$)

Fe$_{49}$Pt$_{41}$Ag$_{10}$-50%C @ 550°C  Fe$_{49}$Pt$_{41}$Cu$_{10}$-C50% @ 550°C

Ag

Cu

$H_C = 35\text{kOe}$
$K_u = 4.3 \times 10^7 \text{erg/cc}$

$H_C = 21\text{kOe}$
$K_u = 4.2 \times 10^7 \text{erg/cc}$
Sputtering using an alloy target

(Fe_{47.5}Pt_{47.5}Ag_{5})-50\text{vol\%}C

ICP:(Fe_{56.6}Pt_{41.0}Ag_{2.5})-C

d=6.4\text{nm}

Cosputtering

(FePt)_{0.9}Ag_{0.1}-C50\%

d=6.1\pm1.8\text{nm}

\begin{center}
\begin{tabular}{c c}
50\text{nm} & 50\text{nm} \\
\hline
d=6.4\text{nm} & d=6.1\text{nm}
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{c c}
\begin{tabular}{c}
\text{m (emu/cc)}
\end{tabular} & \begin{tabular}{c}
\text{M (emu/cc)}
\end{tabular} \\
\hline
\begin{tabular}{c}
\text{H (kOe)}
\end{tabular} & \begin{tabular}{c}
\text{H (kOe)}
\end{tabular}
\end{tabular}
\end{center}
Summary

• FePtAg-C granular film with $H_c = 35$ kOe and good squarness was obtained. ($d \approx 6.2 \pm 1.4$ nm)

• Few FePtAg particles grow on one MgO grain. No 1:1 correlation.

• Ag dissolved in the FePt particle.

• $T_c$ of FePtAg-C is 460-480°C.

• TAR static test at HGST demostrated 530 Gbit/in$^2$

• Similar microstructure can be produced by sputtering alloy targets
Future Direction

• More effort in optimizing the nanogranular structure in a laboratory scale
  • $D \sim 4$ nm, $\delta < 10\%$, better SFD
• Better choice for spacer materials for columnar growth
• Metallic interlayer instead of MgO
• Effect of thermal conductance of substrate and interlayer on TAR density
• Effect of exchange coupling on SFD


• Suggest parameter choice in industrial production of FePt granular media using alloy targets