Our Vision for Particulate Magnetic Tape in the Year 2015

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Particulate Magnetic Tape in the Year 2015

Our Vision

Data cartridges with storage capacities exceeding a 10 terabytes
Particle sizes less than 50 nm with a polydispersity less than 5%
Particle volume fractions exceeding 50%
Highly ordered, self-assembled particles
Magnetic film thickness less than 50 nm
New particles, beyond iron
Base films with thickness of one micron or less
Solventless coating processes that eliminate air pollution in tape manufacture
Sustainable manufacturing and materials packages, using renewable resources

THE UNIVERSITY OF ALABAMA
Magnetic Tape

Made by a double slot-die coating process

- Basefilm: 6.8 µm
- Magnetic layer: 350 nm
- Under layer: 1.5 µm
- Back coat: 500 nm

The magnetic layer contains iron particles, the particles should be oriented parallel to the length of the tape.

The under layer contains TiO₂ particles.

The back coats contain carbon black for anti-static.
Commercial Iron Particles

The particles

• are not perfect single crystals protected with a uniform coating of aluminum oxide, but are chains iron particles

• have a log normal distribution of sizes with a line width parameter of 0.25 to 0.35
Cryo-TEM images of MP Ink

We are not making ideal dispersions

- The particles form bundles with tens of particles in a bundle
- The bundles form a sample-spanning network
Orientation Distribution for a DLT IV Tape

Sample Number UA-DLT IV-001

The particles are not all perfectly aligned parallel to the length of the tape

Fit the distribution function to a Gaussian

The linewidth of the distribution function is 32°

TEM Cross-section of DLT IV Tape

The thickness of the magnetic layer is not uniform, suggesting instabilities during the double slot-die coating process.
There is Plenty of Room for Improvement

• Smaller particles with narrower particle size distributions
• Better dispersions
• Thinner, smoother coatings
• Control of the rheological properties of the coating fluids
• Control of fluid mixing and interfacial instabilities
Evolution of the Materials Package

Acicular Iron Particles

- Smaller particles
- Narrow particle size distribution (polydispersity less than 10%)
- Predispersed and surface treated
- Self-assemble into highly ordered arrays under conditions or shear and/or magnetic field.
Self-Assembly of Magnetic Particles

Computer simulation

- orienting in an applied magnetic field
- forms a smectic-like structure
- ability to order depends on the polydispersity of the particle lengths

Self-Ordering Magnetic Dispersions

A. S. Bhandar and J. M. Wiest
Department of Chemical Engineering
University of Alabama

• Suspensions of well dispersed, identical magnetic particles spontaneously self-assemble into ordered structures.
• The most stable structure has nematic order with all of the particles aligned in a particular direction.
• This order is enhanced by magnetic fields or deformation.

\[ S = \sqrt{\frac{9}{2} \text{tr}(S \cdot S \cdot S)} \]

\[ S = \langle uu - \frac{1}{3}\delta \rangle \]
New Magnetic Particles Beyond Iron

Small Size (< 10 nm)
High Coercivity (>2500 Oe)
Easily Dispersed
Self-assemble into Close-Packed Arrays
FePt Nanoparticles

One of the CHEMISTRY HIGHLIGHTS 2000 cited in Chemical & Engineering News, December 18, 2000, pp. 30-31

Self-Assembled $[\text{Fe}_{49}\text{Pt}_{51}]_{88}\text{Ag}_{12}$ Nanoparticles

We have prepared $[\text{Fe}_{49}\text{Pt}_{51}]_{88}\text{Ag}_{12}$ nanoparticles by the simultaneous reduction of $\text{Pt}^{2+}$ and $\text{Ag}^{+}$ and thermal decomposition of $\text{Fe(CO)}_5$.

These particles self-assemble into hexagonal close-packed arrays.

The annealing temperatures for FePt nanoparticles can be reduced by 100°C to 150°C by the addition of Ag.

This suggests the possibility of annealing the particles in dispersion.

Self-Assembled Magnetic Tape

Cast the dispersion onto polymeric substrates and dry in such a way as to achieve highly ordered magnetic particles.

- Particle diameter 3 to 5 nm
- $H_c > 3000$ Oe

Before Annealing

Annealed at 400°C for 30 min
A Fundamental Knowledge of the Constitutive Behavior of Magnetic Tape

Thinner, smoother tape composed of smaller, better oriented particles must be able withstand increasingly demanding conditions in faster drives and libraries.

This requires understanding the mechanical properties of the tape and how those properties are influenced by the materials package — the constitutive behavior of the tape and how it depends on tape structure.

This understanding will facilitate modeling of the tape pathways and assist in drive design.
Constitutive Relations for Magnetic Tape

David E. Nikles and John M. Wiest
Center for Materials for Information Technology
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A structural-based model that describes the mechanical properties of magnetic tape

\[ \pi - p \delta = \left( \frac{2}{3} \left[ G - K \right] \right) (\gamma^0 - \gamma^0) - G_1 S_t \rho \left( S + \frac{1}{3} \delta \right) \]

Particle Order

\[ + \frac{G}{3} (N + B - 3) S + G (N + B) \left[ S : S - S : S \left( S + \frac{1}{3} \delta \right) \right] \]

Constitutive Relations
A Fundamental Understanding of the Double Coating Process

Understanding the nature of the coating flows

Effect of the rheological behavior of the coating fluids

Understanding the fluid instabilities in the coating process

Interfacial instabilities leading to non-uniformities

The most important interface is the one between the magnetic coating and the undercoat

Leads to an ability to make thinner, smoother magnetic coatings
Base Film Materials for Magnetic Tape

Polyester (Polyethylene terephthalate) has been the leading material

Alternatives

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength (MPa)</th>
<th>Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene Terephthalate (PET)</td>
<td>221</td>
<td>4.3</td>
</tr>
<tr>
<td>Polyethylene Naphthalate (PEN)</td>
<td>222</td>
<td>5.4</td>
</tr>
<tr>
<td>Polyimide</td>
<td>227</td>
<td>4.8</td>
</tr>
<tr>
<td>Polyaramide</td>
<td>200</td>
<td>9.8</td>
</tr>
<tr>
<td>Polybenzoxazole (PBO)</td>
<td>511</td>
<td>16.8</td>
</tr>
</tbody>
</table>

Data provided by Professor B. Bhushan, The Ohio State University

The industry does not expect to get base films with a thickness less than 4 microns

This threatens to limit the volumetric storage capacity of magnetic tape

As the base film gets thinner, it is more difficult to handle
Get Rid of the Base Film!!

A new double coat process

Simultaneously cast an ultrathin magnetic coating (100 to 200 nm) and a thicker undercoat (1 μm) onto a release film.

The magnetic particles are oriented

The dual layer is cured by uv or e-beam radiation

The dual layer is separated from the release film

Gives a 100 to 200 nm thick magnetic layer on a 1 μm base film

The base film thickness tracks the industry’s ability to make thinner undercoats
Portfolio of Research Projects

Science in Pursuit of the Vision

New Binder Polymers Nikles
Particle Chemistry Nikles
Magnetic Dispersions and Simulation Lane, Nikles, Visscher and Wiest
Tape Coating Process Johnson, Nikles and Wiest
Pollution Prevention in the Magnetic Tape Industry Nikles
Tape Characterization Harrell, Nikles and Wiest