Outline

- Areal Density Trend
- PMR Introduction
- Key Advantages and Challenges
- 146 Gb/in² demo to 80 GB/2.5”P Product
  - Shielded Pole
  - BER and Linear Density
  - ATI
  - Track Density
  - Pole Erasure
  - External Field Sensitivity
  - Thermal Stability
- Conclusions and Outlook
PMR Enables Areal Density Growth

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<tr>
<th>Year</th>
<th>Industry AD Trend '91 to '98 (60% CAGR)</th>
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Source: IDC

- **WD 80 GB/2.5”P PMR Product**
- **GMR**
- **AMR**
- **Inductive**
- **146 Gb/in² PMR demo**
- **PMR/TuMR (CAGR to 40%)**

30% CAGR to date

Source: IDC
Perpendicular Magnetic Recording (PMR)

- Advantages of PMR
  - Media “inside” of head gap, providing higher writing fields (up to 2X)
  - Reduced demagnetizing influence of adjacent bits, improves thermal stability
  - Higher amplitude due to higher media MrT
  - Solution for recording densities as high as 1 Tb/in²
Key Challenges for PMR Productization

- **Shielded pole head**
  - Critical dimension control
- **Adjacent Track Interference (ATI) and Wide Area Track ERasure (WATER)**
  - Double Reverse Coil Design
- **Media is part of the head**
  - Head/media matching is more important
- **Footprint recording (PMR) vs. gap recording (LMR)**
  - Bevel angle control
- **Pole Erasure**
  - Shape anisotropy and film properties
- **Stray field**
  - Pole and shield optimization
- **Drive Integration**
  - DC free servo; channel optimization; media corrosion
Turning PMR Technology Demonstration in Product

- 146 Gb/in² density demo
- Nov. 2002 press release
- Monopole PMR writer
  - Single layer coils
- GMR reader
- Fixed Spacing 10 nm
- 772 KBPI
- 189 KTPI
- BAR 4.1
- BER of $10^{-5}$

- 80 GB/2.5” platter product
- July 2006 production
- Shielded Pole PMR writer
  - Double reversed coils
- GMR reader
- DFH (Dynamic Fly Height)
- 1025 KBPI
- 140 KTPI
- BAR 7.3
- Typical BER of $10^{-9}$ or better
Head Design Comparison

146 GB/in² Demo

80 GB/P Product

ABS View

Cross Sectional View
WD Shielded Pole Design for PMR

1st in industry to successfully implement shielded poles (US Patent #7,126,790)

Shielded design advantages over monopole designs:
- Higher SNR obtained with shielded pole design
- More tolerant to imperfect easy axis orientation in the media.

Monopole Writer is a simpler structure
- Does not have the top shield and coils
- Higher write field, but poorer write characteristics

~ 2-3 order of BER and
~ 200 KFCI improvement

Presented @ IDEMA 2004
Double Reverse Coils Design

Double Reverse Coils (US Patent #7,126,788) for low ATI and WATER

Minimal WATER at both spin stand and drive

Minimal ATI at both spin stand and drive
146 Gb/in² demo: PMR has 10 % TPI than LMR using the same reader physical track width

80 GB/P product: Uses the same reader physical track width as in 60 GB/P LMR product. 10 % TPI improvement realized.
Pole Erasure Robustness

146 Gb/in² demo:

No pole erasure up to 1000 write iterations and at room temperature

80 GB product:

• Accelerated stress testing on pole erasure:
  • Max write currents and overshoot
  • DC erased background
  • No degauss in preamp
  • Operating DFH powers at write/read
  • Temperature from 10°C to 45°C
  • External field up to 100 Oe
  • Write up to 1 million iterations

Improved material/design/process

No pole erasure up to $10^{20}$ write iterations and at $60^\circ$C
Pole Erasure and DFH

- DFH induced stress and/or heat may cause pole erasure
- Great care has been taken to ensure product margin against DFH
Stray Field Margin

Operational drives in the middle of GMW Uniform Field Electromagnetic model 5451 with various orientations shown.

No BER degradation with stray field as high as 110 Oe in all directions.
Media Thermal Stability

- PMR media shows excellent thermal stability compared to LMR
  - Below plot at the same areal density for PMR & LMR
Western Digital’s 1st TuMR Drive

- Current Perpendicular to the Plane
- >5X Amplitude of GMR
- Better Reliability than GMR
- 160 GB/3.5” Platter Drive
- July 2006 production
- Al₂O₃ TuMR Reader
- LMR Writer
- DFH
- 850 KFCI
- 140 KTPI
- 950Mb/sec

Courtesy of Curtis V. Macchioni
Conclusions

- PMR product is a reality with expected advantages realized and key challenges overcome
- WD is ramping PMR against its strategy
  - Time to quality: Deploy new technologies when critical balance of cost, reliability, quality is met, while meeting customer needs
  - First to market is not necessarily best: mature technology minimizes customers’ Total Cost of Ownership (TCO), maximizes manufacturers’ ROI
  - Early and focused technology development
    - WD is the first to demonstrate PMR shielded pole feasibility
    - WD is the first to demonstrate PMR double reverse coils feasibility for ATI/WATER robustness
    - 146 Gb/in² areal density demo in 2002
    - Manufacturing maturity

- Acknowledgment: William Cain and Curtis Macchioni