TeraStor's Near-Field Recording

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TeraStor Corporation

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TeraStor Corporation Background

- **TeraStor founded December 1995**
  - » **Jim McCoy - CEO (founder of Maxtor, co-founder of Quantum)**
  - » **Gordon Knight - CTO (founder of Maxoptix & Optimem)**
  - » **Bill Dobbin - CFO**
- **Initial Seed Funding - February 1996**
  - » **Demonstrate Near Field technology June 1996**
- **First Round Financing - July 1996**
  - » **Begin full staffing of engineering team**
  - » **Initiate product development**
- **Over $85M investment to date**

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TeraStor Mission

- **To deliver a new class of storage products, providing the highest areal density, based on near-field recording and the solid immersion lens.**
- **To develop and introduce products with target capacities approaching 20 gigabytes per disk surface.**
- **To develop product families with both removable and fixed media.**

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Near Field Recording - Technology Evolution

- **Optical flying head/First surface recording**
  - » **Basic technology developed by Digital.**
    - – **Extensive patent portfolio (26 patents)**
  - » **Patents acquired by Quantum as part of their acquisition of the Digital storage business**
  - » **Co-exclusive patent rights granted to TeraStor by Quantum**

- **Solid Immersion Lens (SIL) technology**
  - » **Basic technology developed and patented at Stanford University**
  - » **Exclusive patent rights granted to TeraStor by Stanford**

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Conventional Optics Overview

- An optical lens bends light according to the index of refraction (n) of the lens material
- Numerical Aperture, which limits the focused spot diameter is defined as:

$$NA = n \operatorname{Sin} \theta_{max} \text{, which means } NA \leq 1 \text{ (in air)}$$

- The highest commercially practical NA achieved to date is .65, common magneto-optical drives use NA $\cong$ .55
- The diameter of a focused spot of light is dependent on the wavelength of light and the NA of the lens and is defined as:

$$d \cong .5\lambda/NA$$

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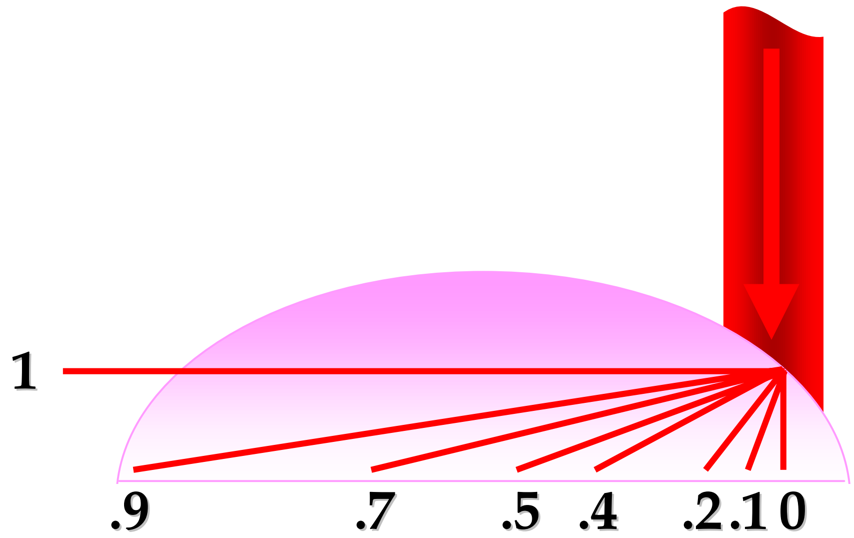
Numerical Apertures



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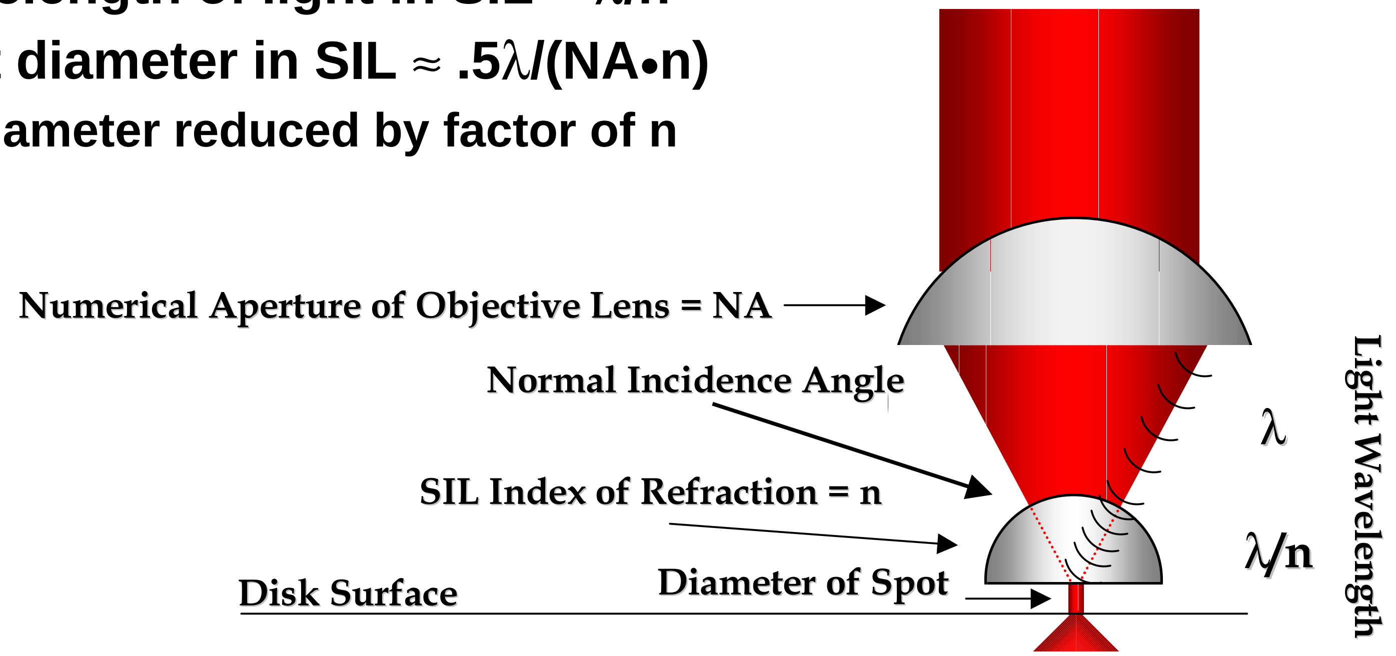
Near-field Optics

- Spot Diameter without SIL ≈ $.5\lambda/NA$
- Light entering SIL is not bent but is slowed by a factor of n compared to air
- Wavelength of light in SIL = λ/n
- Spot diameter in SIL ≈ $.5\lambda/(NA\bullet n)$
  - » Diameter reduced by factor of n



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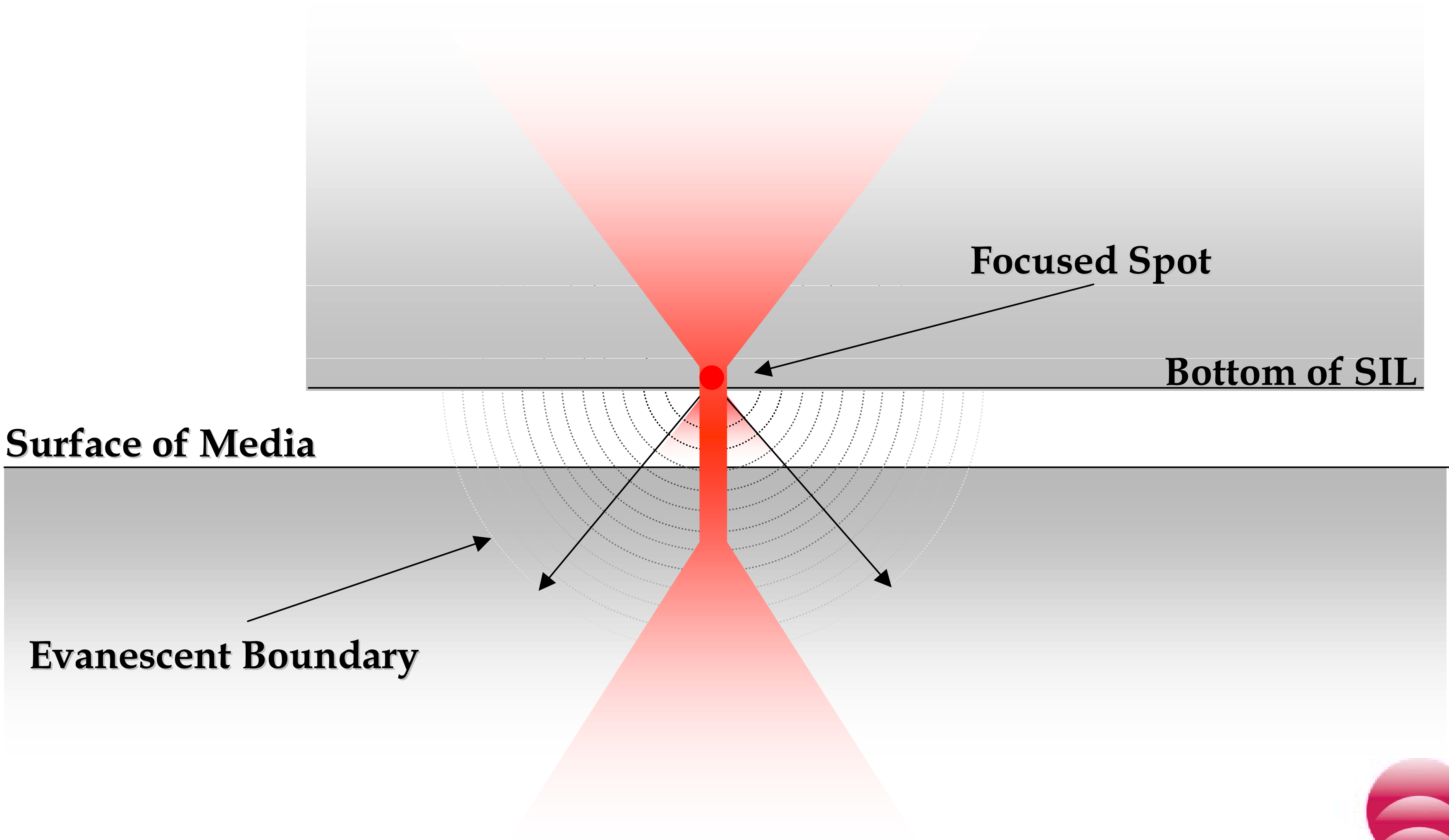
Evanescent Coupling

- **Provides energy transfer from the SIL to the surface of the media**
  - » **Unlike conventional magneto-optical products, the laser is not focused on the surface of the media, instead it is focused at the bottom of the SIL**
- **Well understood from Near-field Scanning Optical Microscopy**
- **Allows image of small spot inside SIL to be pulled to the surface of the media.**

Evanescent Fields



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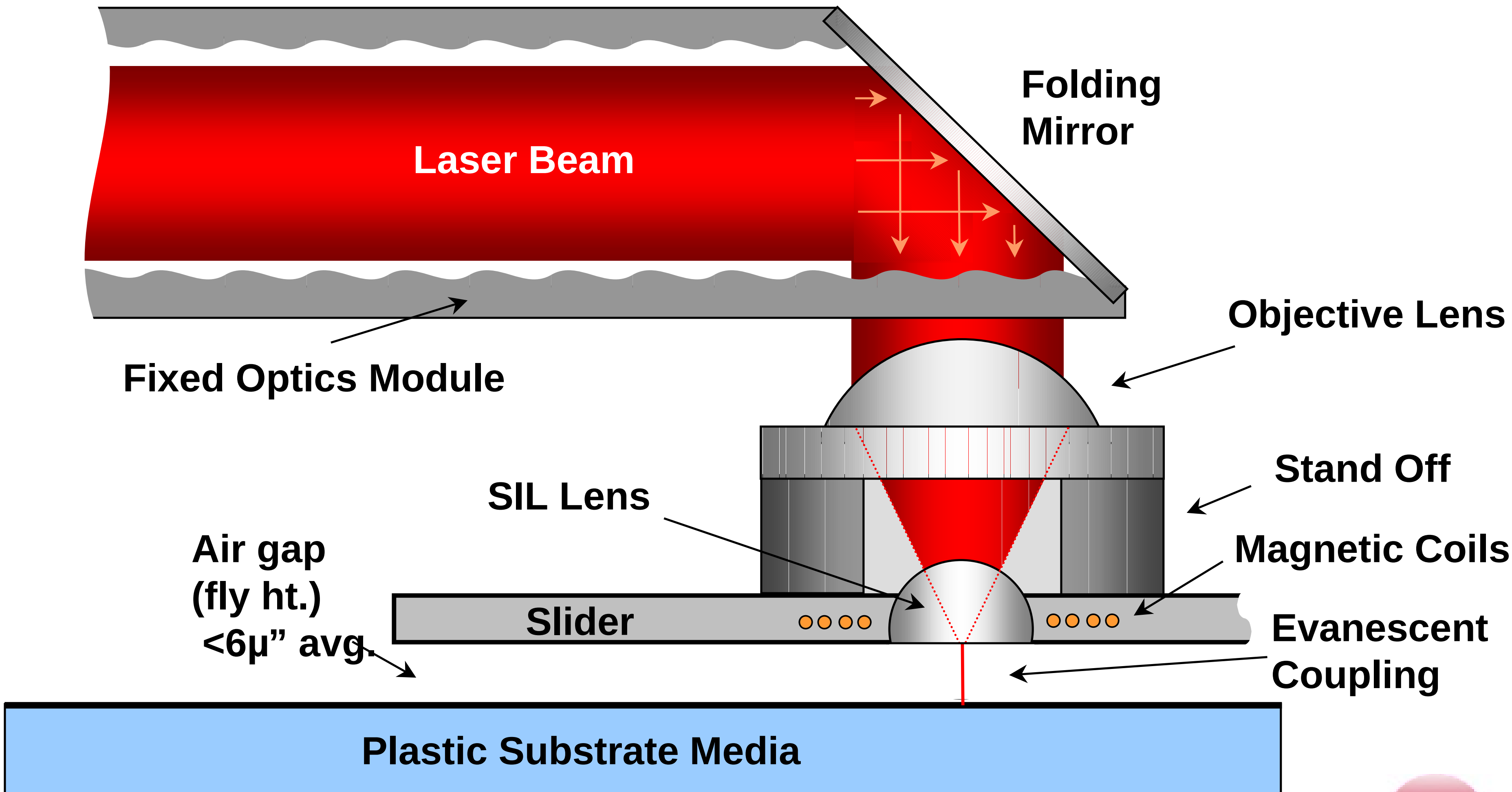
NFR Components

- **Solid Immersion Lens**
  - » **Based on liquid immersion microscopy**
  - » **Allows Numerical Aperture of much greater than 1 by using high index of refraction material**
  - » **Shape of the SIL allow for tighter focus of light spot**
- **First Surface Recording**
  - » **Places recording films in near-field proximity to the head**
- **Flying Optical Head**
  - » **Provides tight focus tolerances within the near-field and eliminates focus servo found in conventional magneto-optical products**
- **Crescent Recording**
  - » **Allows for bit densities of > 200,000 bits per inch with SIL**

Architecture of TeraStor's Near-Field Recording Technology



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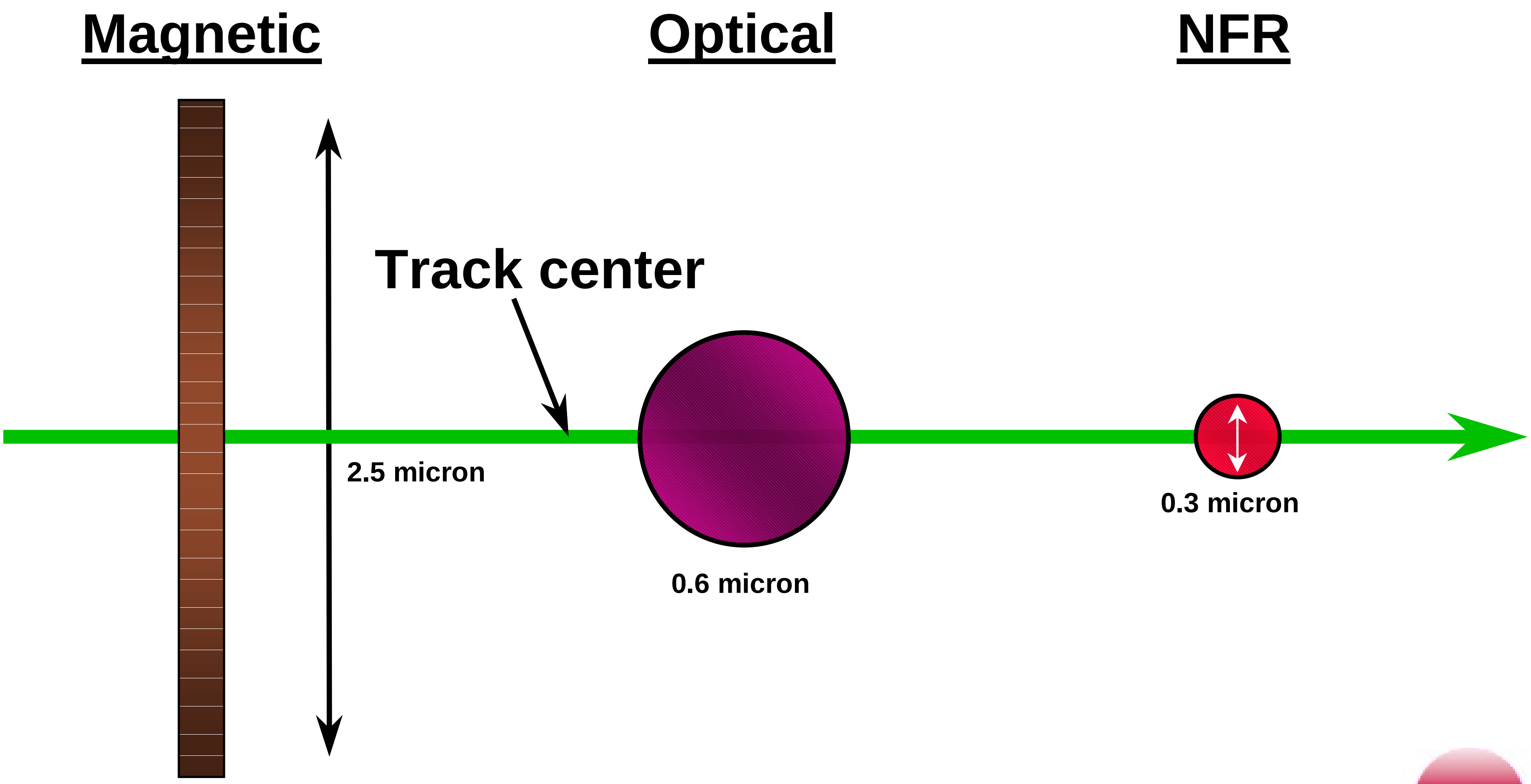
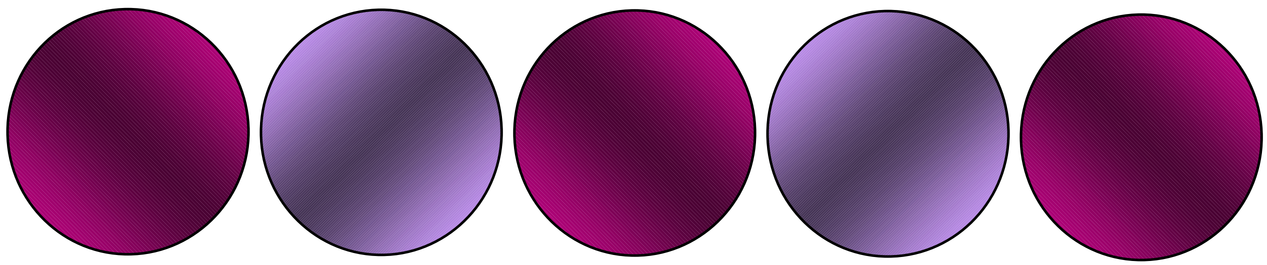
Recording Area Compared

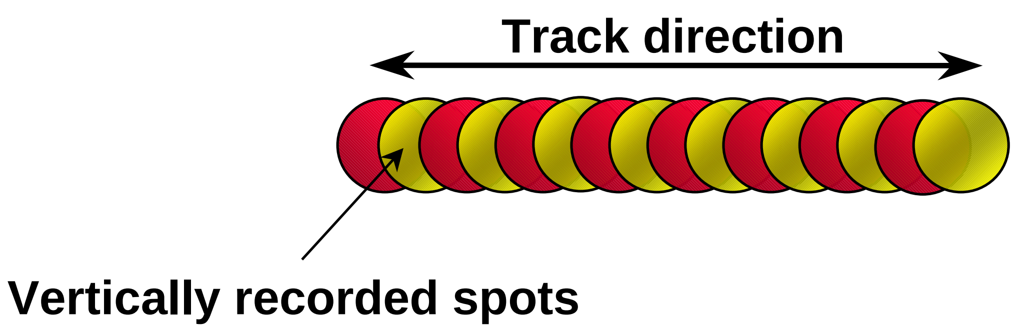


Crescent Recording Increases Linear Density

Traditional Optical



Crescent Recording



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NFR Media

- Uses conventional MO recording films
- Stamped plastic substrate and first surface recording allows media costs to be competitive with tape
- Vertical magnetic domains allow for smaller spots than magnetic recording
- Proven domain stability, no super-paramagnetic effects
  - » Magnetic recording domains become unstable at room temperature somewhere between 20Gb/in^2 and 40Gb/in^2
  - » Magneto-optical media has been proven stable at densities beyond the superparamagnetic "limit" (AT&T 1992)
- Long shelf life approaching that of conventional magneto-optical products
- Infinite rewrite passes, unlike phase change media

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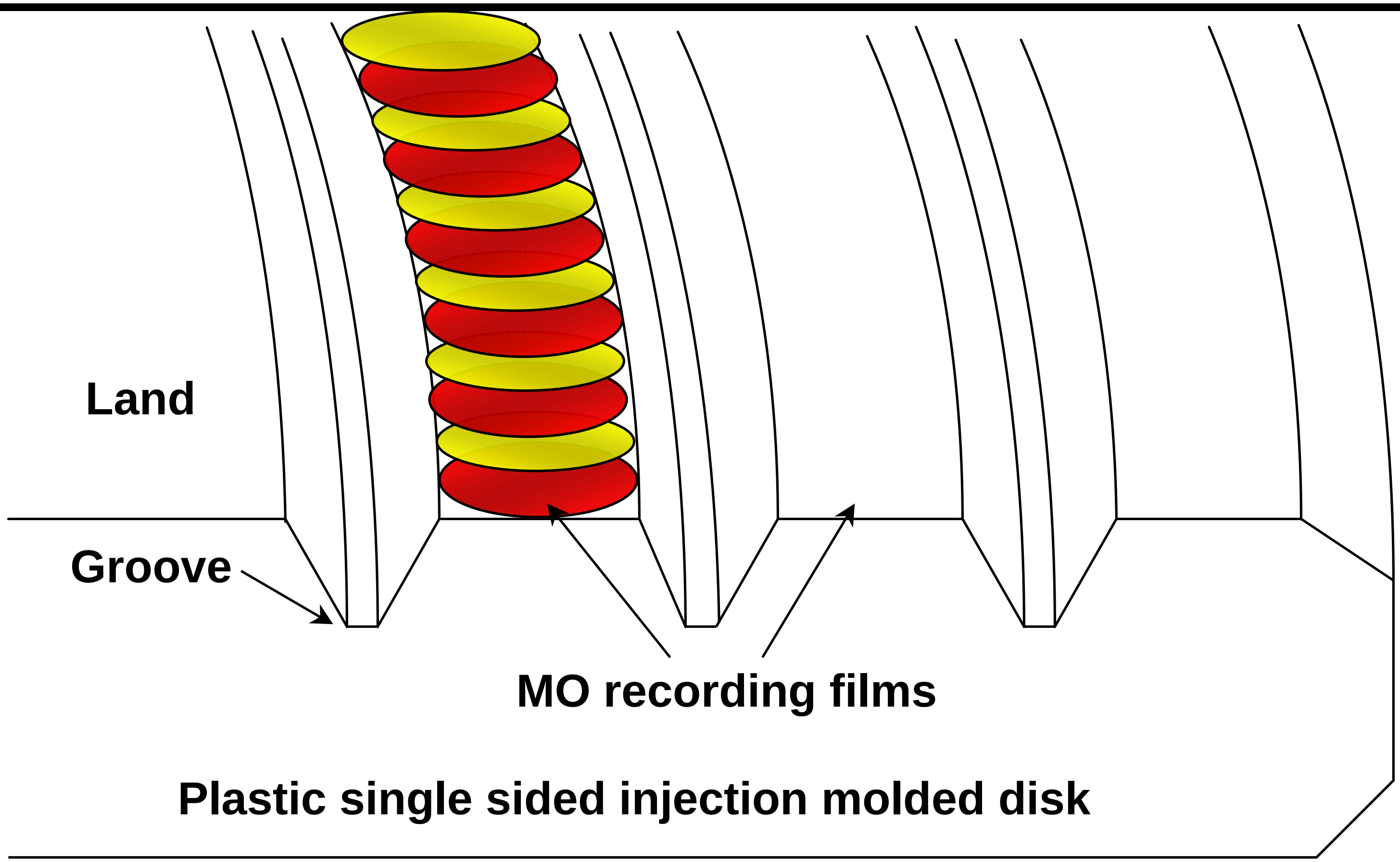
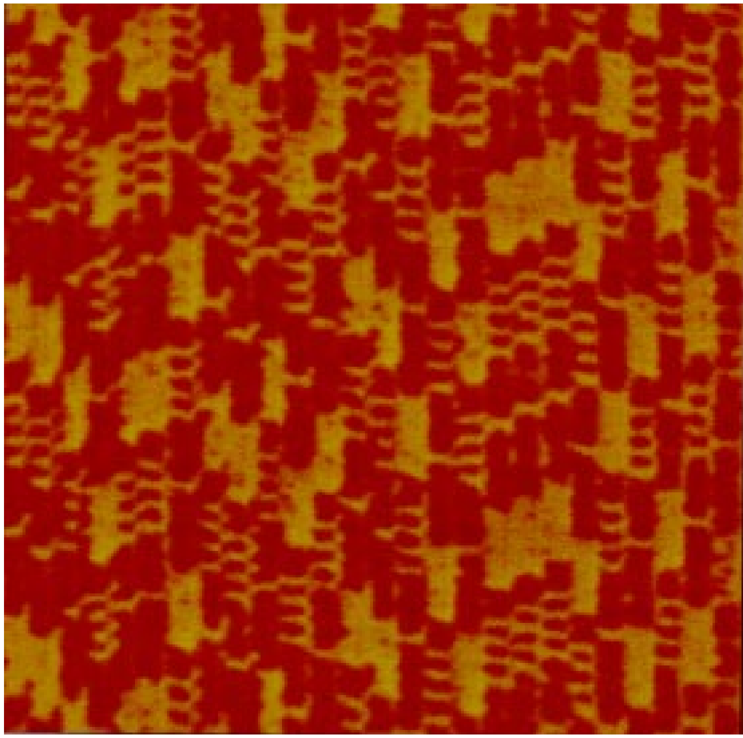
TeraStor Disk Structure

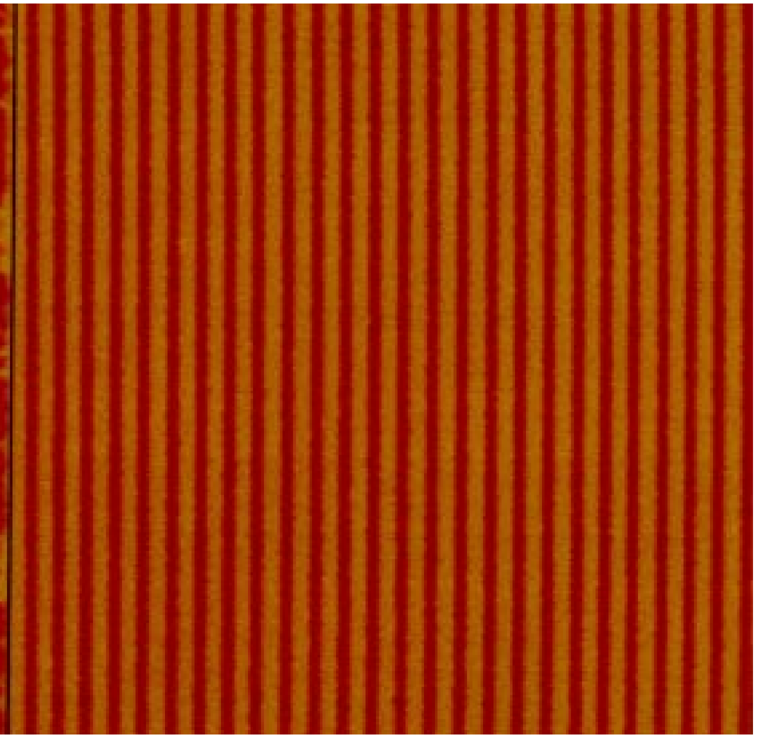


Magnetic Domains

MFM Image



AFM Image



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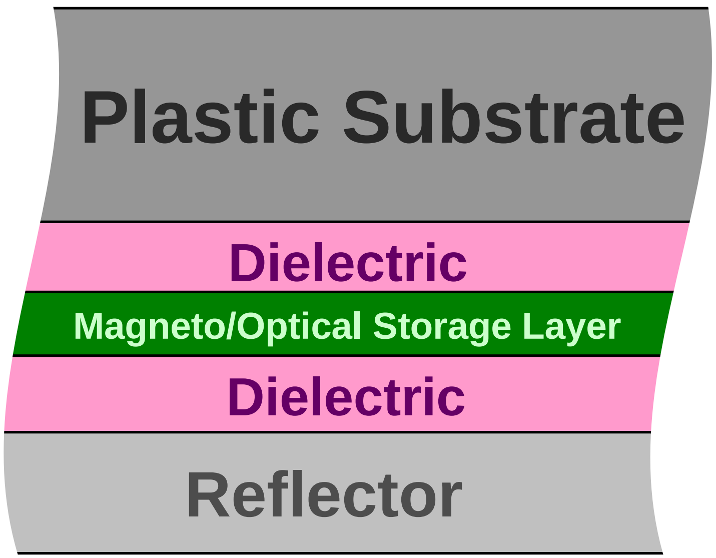
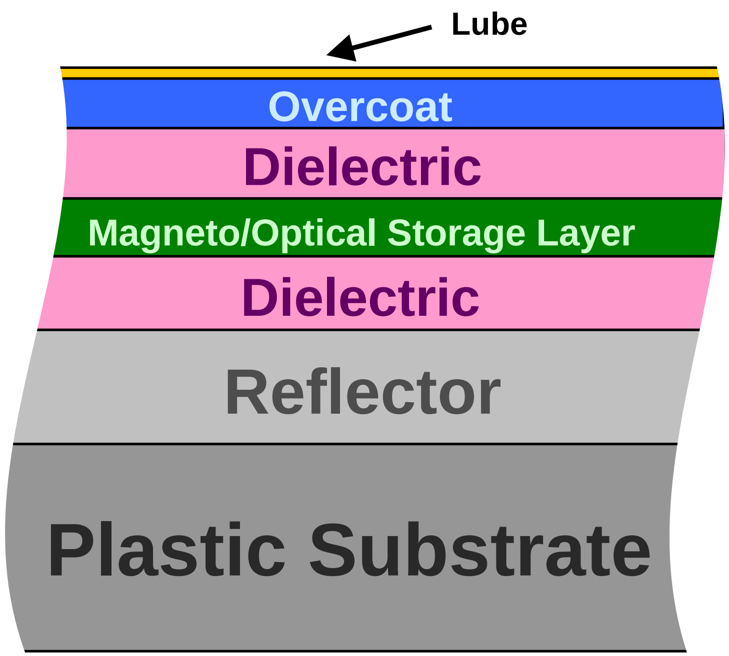
TeraStor Disk Structure

Traditional MO



Near Field Recording



The Two Stage Servo

- **Combines movements of a primary actuator and laser scanning**
- **Radial run out taken out with rotary actuator**
- **Instantaneous near track seeks with galvanometer mirror**
- **High bandwidth micro-mirror galvanometer allows for order of magnitude increase in track densities over magnetic recording**
- **Improved track acquisition capability**
- **Improved shock resilience**

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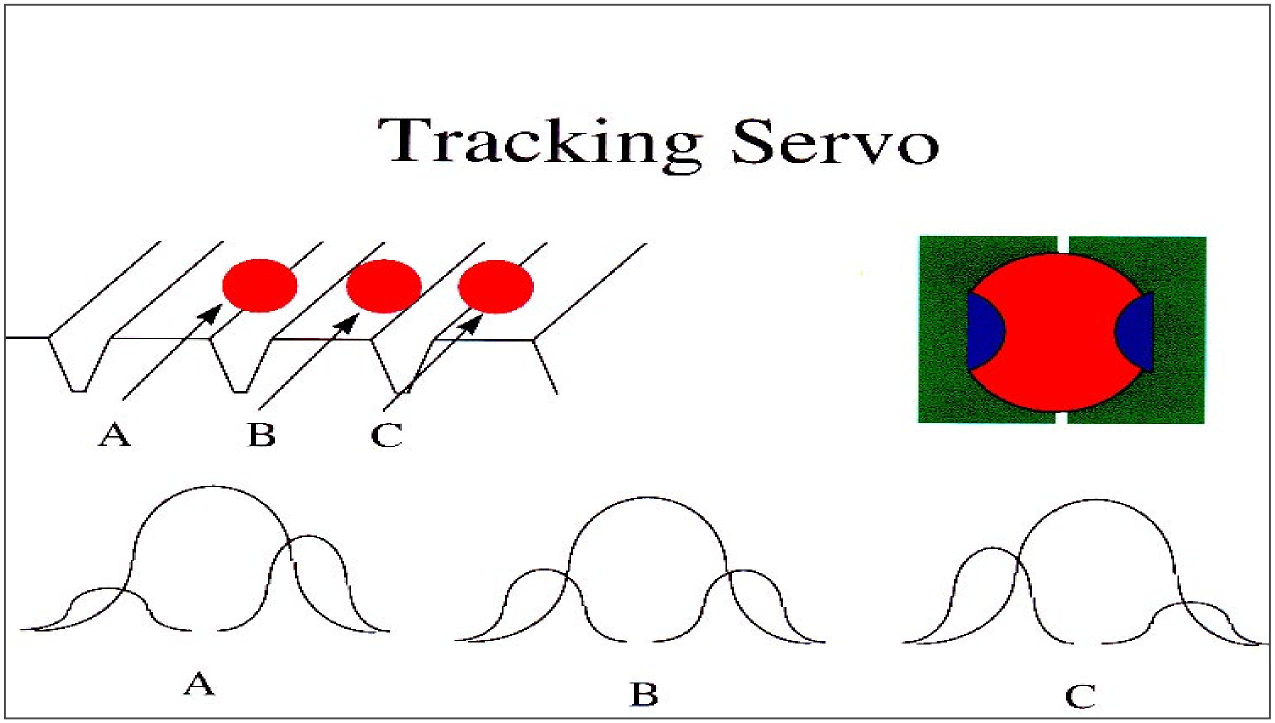
TeraStor Servo Design



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TeraStor Product Highlights

- **High capacity removable cartridge drive**
  - » **target 20GB capacity**
  - » **Removable NFR media**
  - » **near hard disk performance**
  - » **target availability Q498**
- **Announced automation solutions coming from:**
  - » **ATL Products**
  - » **DISC**
  - » **Overland Data**
  - » **Others to follow**
  - » **Exabyte**
  - » **Spectra Logic**
  - » **Plasmon IDE**
- **Storage Management software commitments from 17 UNIX, NT, and Novell backup and nearline application developers**

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Features of TeraStor NFR

- $>$ 10Gb/in^2 with red laser for first product
- ~ 20 GB per disk surface for first product
- Removable and fixed products will be developed
- Desktop hard drive performance
- Known growth path to >100Gb/in^2
  - » different SIL material and shapes
  - » Shorter wavelength laser
- Areal density not limited by superparamagnetic effects

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Optical Comparisons

	Conventional* Magneto-Optical	Near-Field Magneto-Optical	Blue Laser Conventional*	Blue laser Near-Field
Laser Wavelength	685 nm	685 nm	410nm	410nm
Numerical Aperture	0.65	0.65	0.7	0.33
Index of refraction of SIL	n/a	2	n/a	3**
Potential Spot Size	0.53 micron	0.26 micron	0.29 micron	.07 micron
Maximum Areal Density	4Gb/in^2	16Gb/in2	13Gb/in2	238Gb/in2
* Conventional optics products include CD, DVD, ASMO, MO, and OAW			** SuperSIL shape	

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Technology Comparison

	Recording Mechanism	Cyclability	Data Rate	Areal Density
Near-Field MO	Vertical Magnetic Media	Infinite	>160 Mb/sec	> 10 Gb/in^2 today => >200 Gb/in^2
Far Field MO	Vertical Magnetic Media	Infinite	~48 Mb/sec	~ 1Gb/in^2 today => <20 Gb/in^2
Phase Change	Amorpous Crystal Molecular change	10,000 to 500,000 cycles	~ 24 Mb/sec today (slow process)	~ 1Gb/in^2 today => <15 Gb/in^2
Magnetic	In-plane Magnetic Media	Infinite	> 200 Mb/sec today	> 3Gb/in^2 today => < 40 Gb/in^2

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Conclusions

- Near-field recording with a Solid Immersion Lens combines the best advantages of magnetic and optical recording
  - » many components from HDD vendors
  - » Low cost plastic media
- Near-field recording is practical today
- Conventional far-field optical recording has fallen behind magnetic recording and cannot keep up (even for DVD-RAM, ASMO, and OAW)
- NFR technology can maintain a significant areal density advantage over magnetic recording for both fixed and removable media products

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