Research careers: From academia to industry

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Intelligence in Sensing™

Academic vs. Industrial career opportunities

- Students & postdocs in physical sciences (& magnetism) are **naturally familiar with & comfortable in very academic environments**. Most students gain extensive experience in academic institutions, research laboratories, and interact with numerous academic scientists in universities and at conferences. **This dominates their early-career perspectives.**



- The **industrial world remains often more « mysterious »,** in part due to the confidential nature of technical work in most companies. Few students have the opportunity to experience an industrial laboratory or cleanroom.



The goal of this presentation and discussion is to describe my experience in transitioning my early career to industrial R&D.

*It is **one perspective** among many, as the industrial landscape changes quickly.*

Agenda

CROCUS TECHNOLOGY

- Today @ Crocus Technology
- My background and career path
- My thoughts on Academia vs. Industry careers
- Today's industrial environment

- Q&A

Where I work today

- **CTO, Crocus Technology**
- ***Our company mission*****:** Develop and manufacture **the most advanced TMR magnetic sensor solutions** to industrial, automotive, renewable energies, and portable electronics markets.
- ***Our products*****:** Marketed under the **XtremeSense®** trademark, our designs combine **high sensitivity, high bandwidth, low power consumption, and excellent temperature stability -** replacing older magnetic technologies such as coil, Hall effect, AMR or GMR sensors.
- ***My responsibilities:*** TMR technology (materials, sensor design), design), TMR sensor product development, TMR sensor manufacturing, Sensor technology roadmap.

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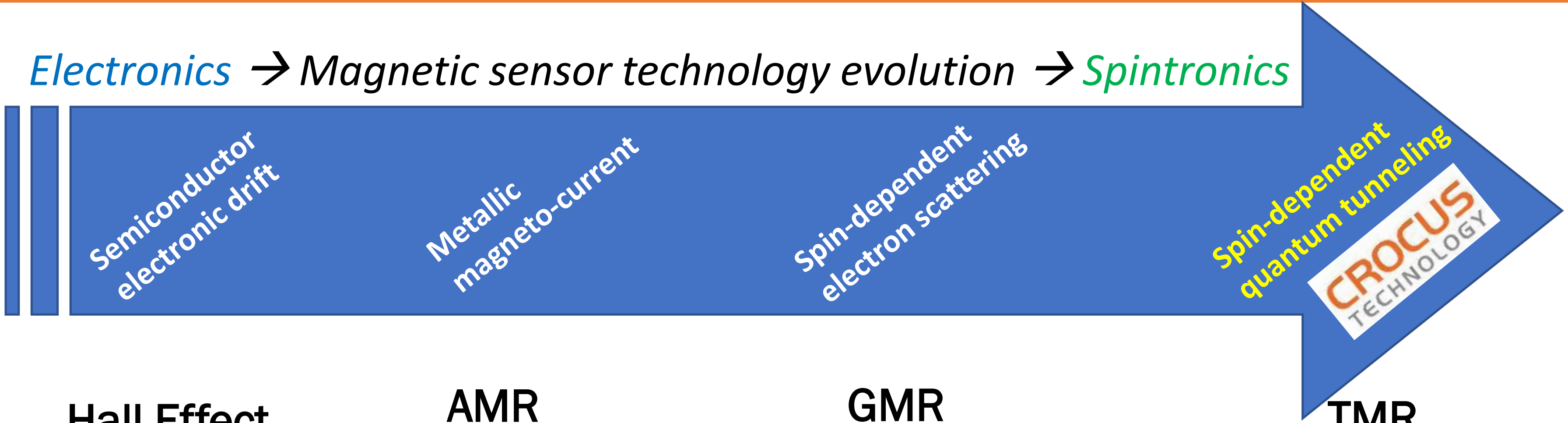
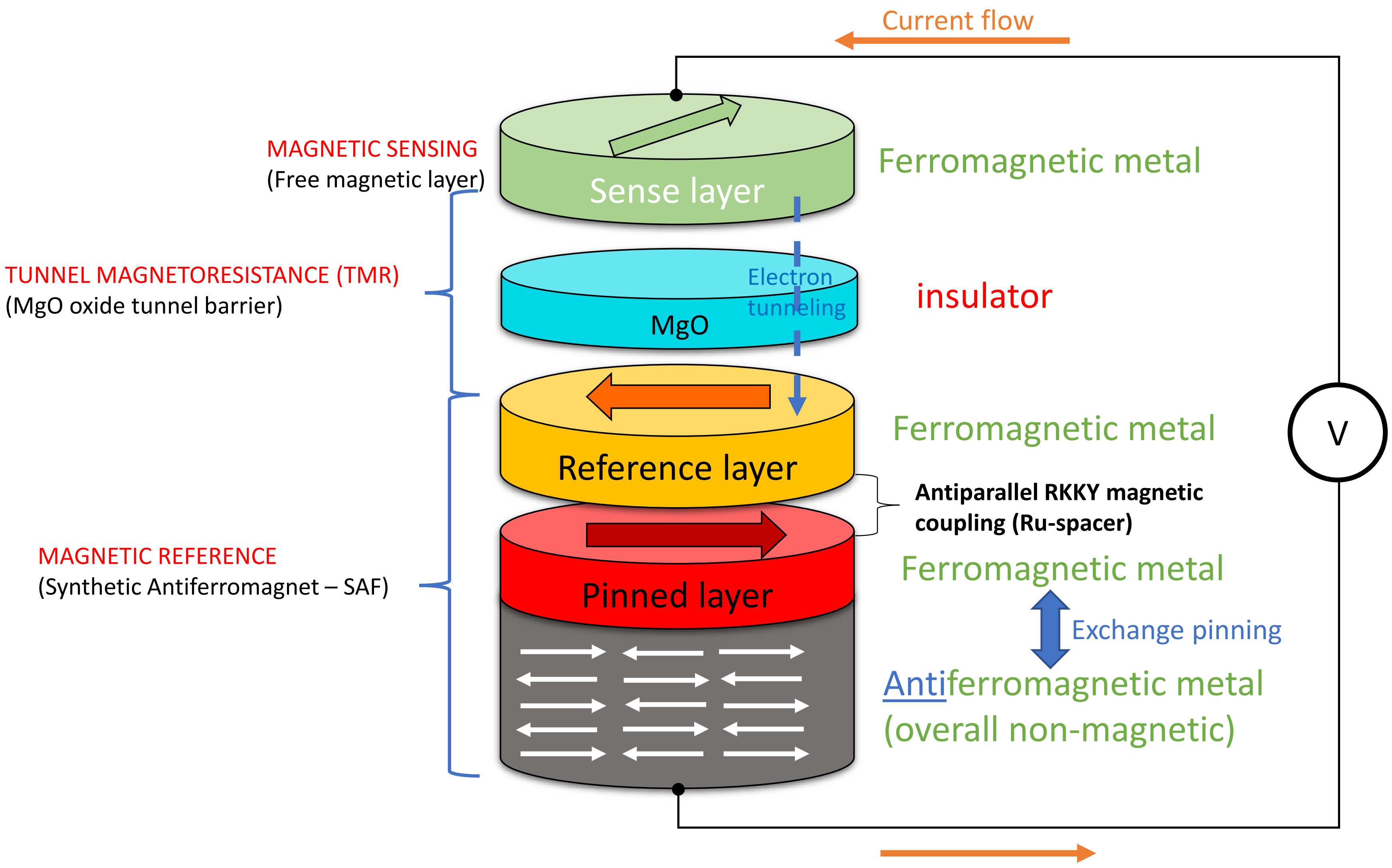
Evolution of magnetic sensors

Electronics → Magnetic sensor technology evolution → Spintronics

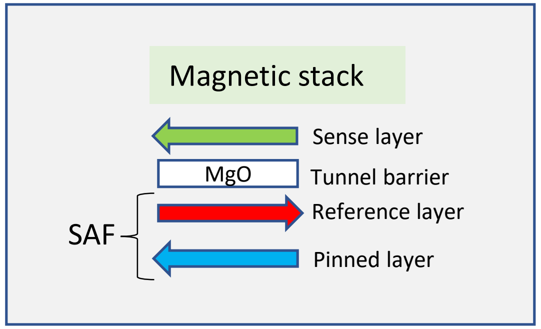


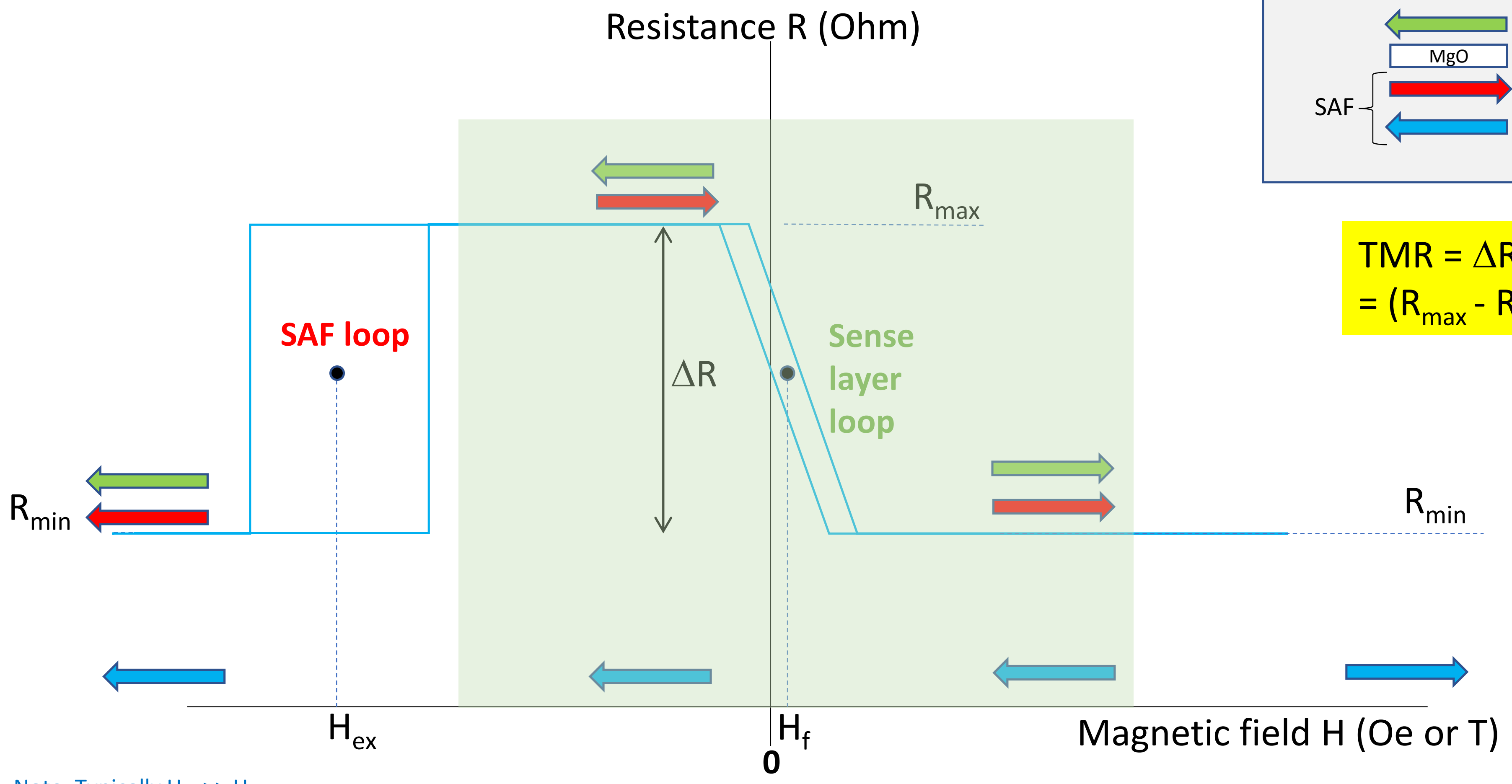
	Hall Effect	AMR Anisotropic	GMR Giant (metallic)	TMR Tunneling
Accuracy	-		+	++
Low Power	-	+	+	++
Temperature Stability	-	+	+	+
Sensitivity	-		+	++
Signal/Noise	-			++

Basic sensor magnetic dot design



High-field Magnetoresistance transfer curve





$TMR = \Delta R / R_{min}$

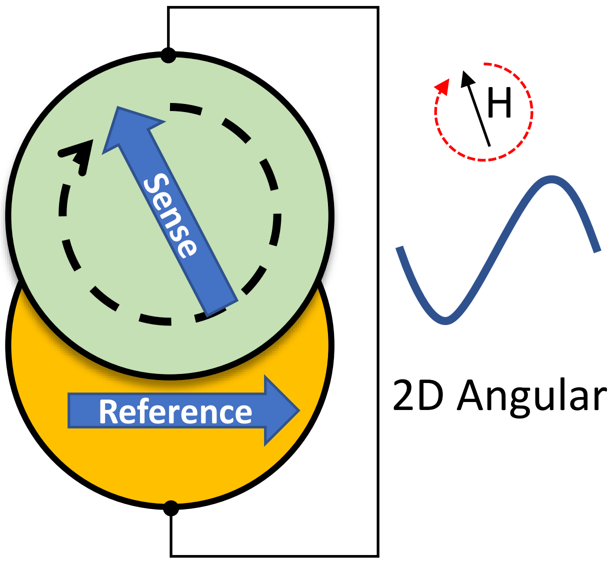
$= (R_{max} - R_{min}) / R_{min}$

Note: Typically $H_{ex} >> H_f$

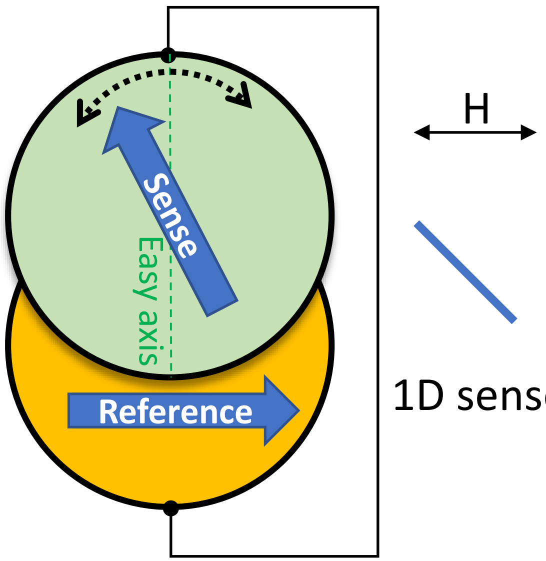
Two applications of magnetic stack (with uniform magnetization)

Sensor layer magnetization rotates freely without a preferred orientation (Anisotropy field Hk < 5 Oe)

Sensor layer magnetization rotates about a preferred orientation (Anisotropy field Hk > 50 Oe)



2D Angular sensor



1D sensor

3 pillars of TMR technology

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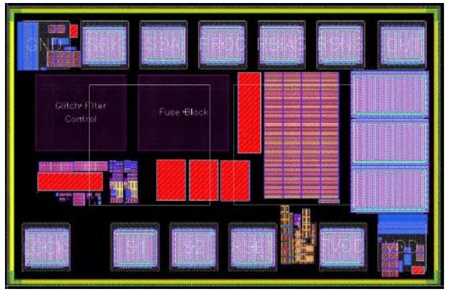
Magnetic stack

ASIC Chip Design

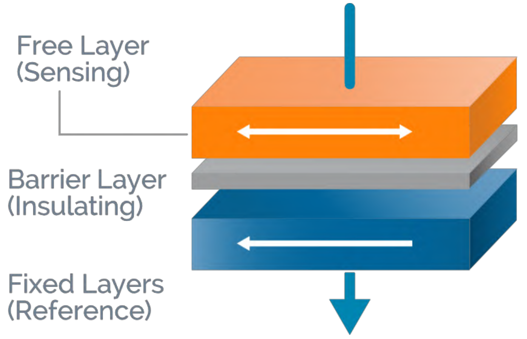


~1 mm^2

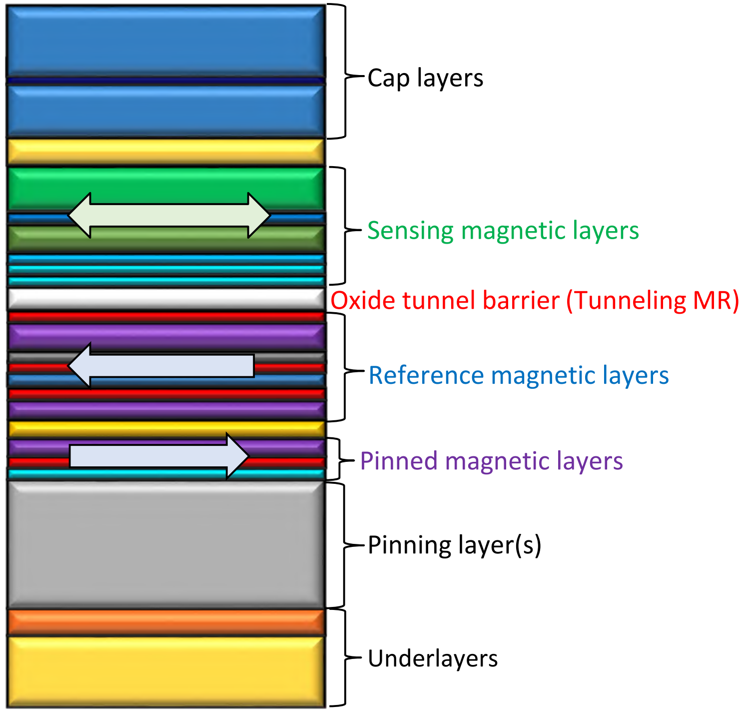
Process & Integration

Technology: Advanced magnetic stack is a competitive advantage

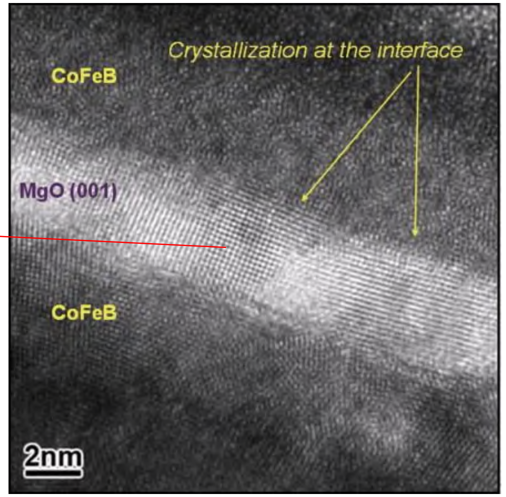
Model



Actual (typical)



C. Park et al, JAP (2006)



- TMR sensor stacks in our products can comprise dozens of layers
- Each layer is 0.1 – 10 nm thick
- Accuracy required to 0.1nm

- TMR tunneling barrier (MgO) requires advanced deposition techniques and extensive processing experience for uniformity of performance on >200mm production wafers.

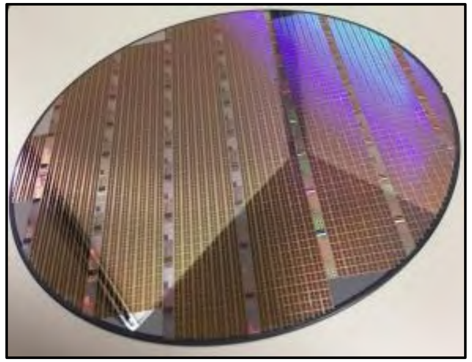
Technology: TMR processing optimization as a competitive advantage

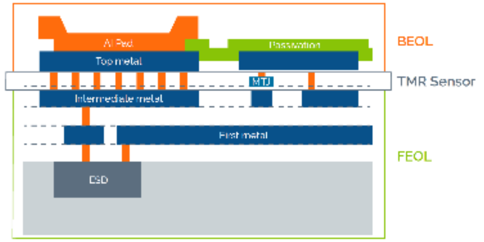
Technology	AMR	GMR	TMR
Deposition tool complexity	+	+++	++++++
Materials complexity			
Process devpt complexity			
Stack complexity			

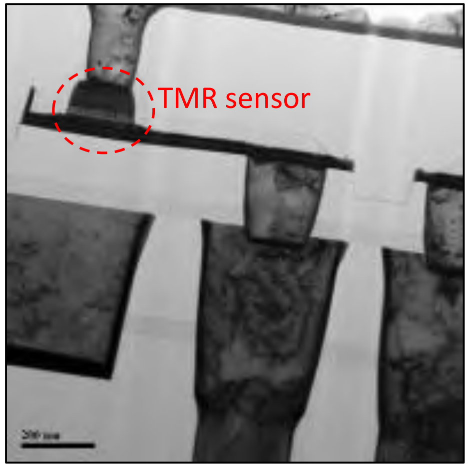
- Advanced TMR product manufacturing on >200mm wafers requires extensive TMR film processing experience, tool optimization experience, and TMR stack integration experience on CMOS circuitry

High-performance TMR needs state-of-the-art thin-film deposition tools

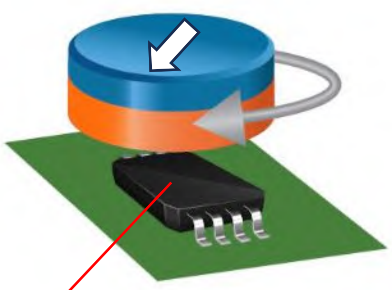
HC7100 | CANON ANELVA CORPORATION



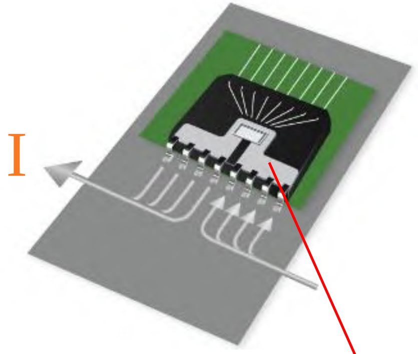




Main TMR products



Position Sensors



Current Sensors

Sensor Solutions

1D/2D Linear Sensors

2D Angle Sensors

Switches & Latches

Isolated Current Sense

Field Sensors

0A~65A: Contact

0A~4000A: Contactless

Customized sensors

XtremeSense® TMR Sensor + Controller with Digital I/O

Strategic markets: Electric current sensor for green energy transition

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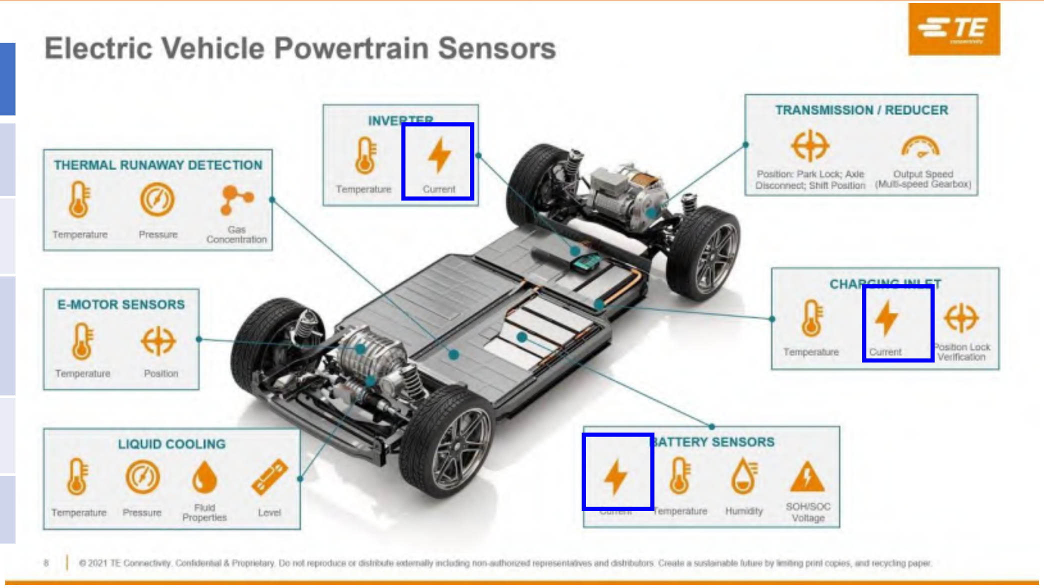
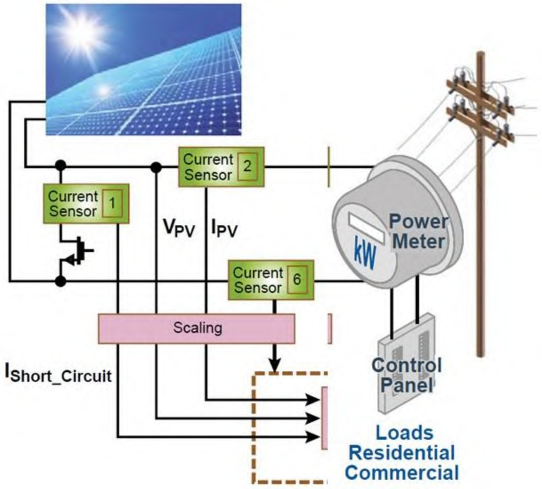
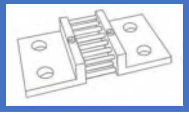
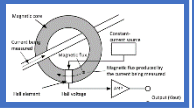
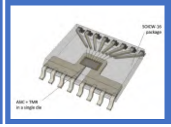
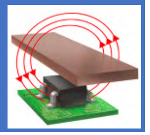
Application	Parameter	Advantage for application
Motor control	Response time	=> higher efficiency
Battery protection	Response time	=> safety (electronic fuse)
Battery Management System	Measurement Accuracy	=> Longer battery life
On-board charger	Response time	=> higher efficiency
Solar Inverter	Response time	=> higher efficiency





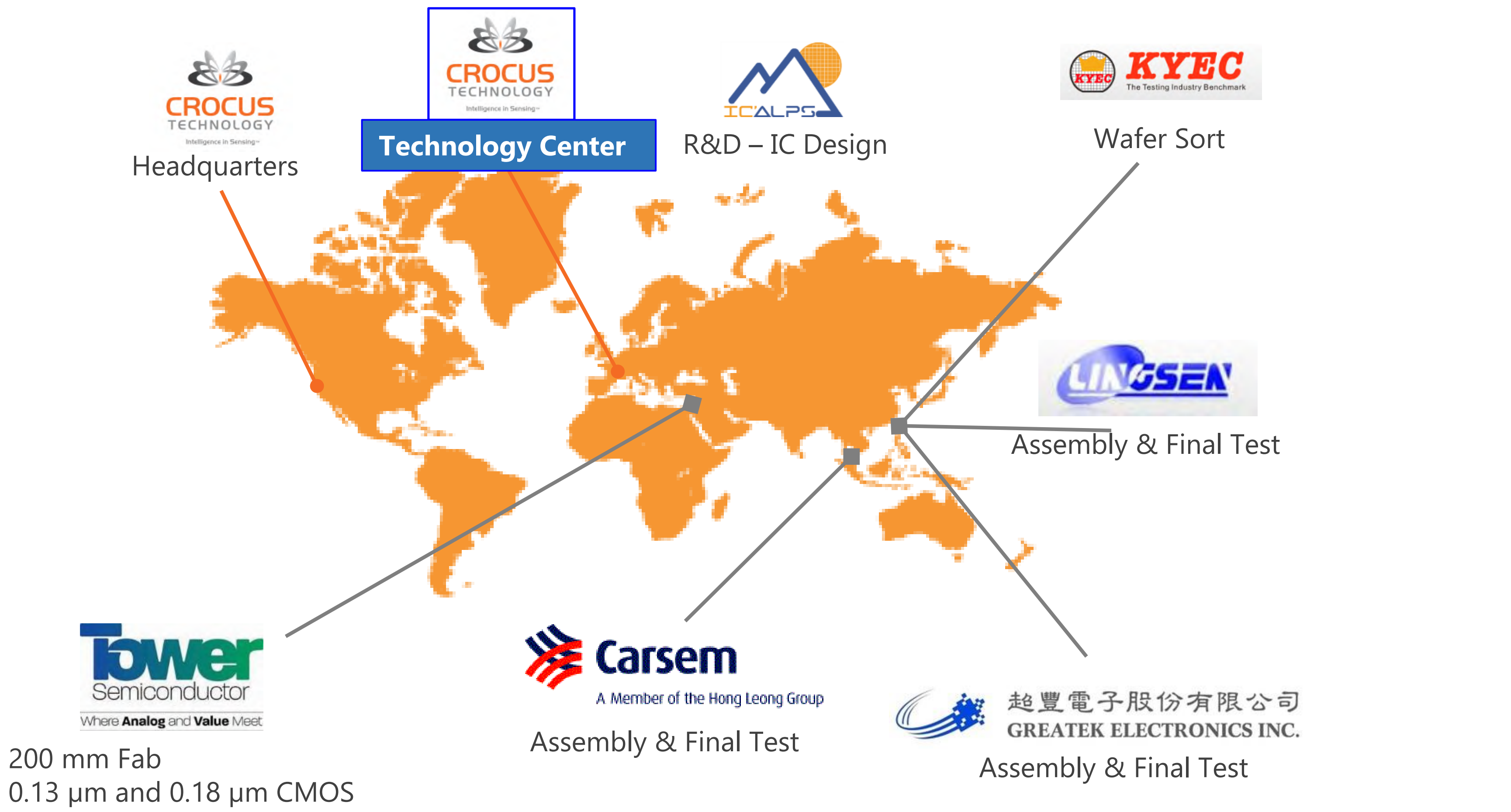
Current-sensor type	Resistive Shunt 	Hall-effect (with field concentrator) 	TMR  
Cost/complexity	++	-	-
Signal amplitude	--	+	++
Energy savings	--	+	+
Accuracy/SNR	++	-	+
Response time/ resolution	+	-	+

CROCUS TECHNOLOGY – Fabless « start-up » company
with international operations

Key facts:

- **Created**: *2004-2005 (MRAM product development), 2015 (Magnetic sensor product development).*
- **Employees** 2023: < 90
- **2022 revenues** ~ $30M
- **Headquaters**: Milpitas (Silicon Valley). USA.
- **Technology center**: Grenoble, France.
- **Intellectual property**:

  >150 patent families



My background: materials physics & magnetism career from Academia to industry

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4 + 6 years	• **Physics Ph.D.** (USA) Experimental condensed matter physics, (nano-structured magnetic materials → structure-property relationships
2 years	• **Post-doc** (France – Univ. Paris-Orsay + Thomson-CSF Research labs) Magnetic multilayers and nanostructures, Giant magnetoresistance (GMR)
5 years	• **Assistant Professor** (USA – Dept of Materials Science and Engineering) Research on magnetic materials for application to magnetic sensors Teaching (Materials Science and Engineering) Received tenure (1998)
5 years	• **IBM Research** (USA - Almaden Research Center) Research staff member, Magnetic sensor materials and nanostructures (GMR, TMR for magnetic recording HDD)
9 years	• ***Sold to Hitachi (Japan)*** → Hitachi Global Storage Technologies Research manager, Sensor materials & technology (TMR, CPP-GMR for magnetic recording HDD)
4 years	• ***Sold to Western Digital (USA)*** → HGST, a Western Digital company Research director, Non-volatile memory materials and characterization (MRAM, RRAM, PCRAM)
7 years+…	• **Crocus Technology** Vice President, Magnetic Devices (TMR sensors) (5 years) Chief Technology Officer (2 years+)

Academic

↓

Industrial

Advantages of Academia

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- Vacation
- Longer, more stable careers
- Tenured professorships (if available)
- Sabbatical leaves (few companies have)
- Long-term independence
- Open scientific environment (talk & publish)
- Conferences & professional societies – can network broadly
- Clear career progression (you are in control)

My academic career

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➢ What I liked about being in academia:

- Enthusiastic students
- Teaching & learning
- Being the boss (of a small domain)
- More opportunity to travel for science (collaborators)
- Long-term freedom to pursue scientific interests
- Able to re-invent yourself and explore new fields

➢ What interested me in industry:

- Always interested in "applied" science - to develop useful technologies or devices
- Liked the team environment of a large company
- Liked the idea of working in a "pay-for-performance" environment
- Wanted to learn more about "industrial" technology & engineering – in the same scientific area (magnetic materials)

➢ How I made the decision to "switch":

Presented with an opportunity… followed what sounded like a unique and exciting path that met my personal interests…no regrets…

The question

To become trained as scientists, we all are “born” in academic environment…

…as a trained scientist, why would you want to consider an industry career ?

1. Get a job (opens many more paths & opportunities)
2. Be happy (very diverse environments will perhaps better suit your own personality and interests)
3. Build your own rewarding career (typically more mobile than academic career)

Industrial career opportunities

1. **Traditional research**
   - Start-up companies → new technologies or new markets
   - Mature companies → new projects or new directions
2. **Product development and improvement**
   - Product Design & Modeling
   - Materials and Device performance & optimization
   - Device fabrication processing & miniaturization
   - Device performance & reliability testing
3. **Product manufacturing**
   - Manufacturing process optimization
   - Manufacturing yield
4. **Product/Project manager**
   - Program manager (internal product project management)
   - Field application scientist or engineer (customer-facing technical sales & support)

My own industrial (R&D) activity breakdown over 25 years

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1. Exploring limits of “recently-implemented” technology: GMR sensors for HDD → Technology improvements to existing products.

2. Developing and demonstrating “new technology”: TMR sensors for HDD → Exploration & transfer of new technology to development team for new products.

3. Fundamental “new technology” development: CPP-GMR sensors for HDD → Exploration and Technology demonstration but no products.

4. Exploratory technology: Fast and efficient solid-state non-volatile memory (RRAM, PCRAM, etc.) → Exploration, left company before product impact.

5. Application of mature technologies to new markets: TMR sensors for automotive and electric-transition applications → New products developed and launched with mature technology.

Industry: It's not about you !

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- **<u>Industry is driven its business imperatives</u>**
  - sometimes business imperatives are decided by executives ← Corporate strategy
  - sometimes business imperatives are decided by the market ← Competition
  - sometimes business imperatives are decided by managers or technical leaders ← Technical direction

- **Different companies have different amounts of "top-down" vs. "bottom-up" drivers.**
- **Best companies to work for** have <u>both</u>:
  - strong corporate strategy ("top-down")
  - and strong technical management team + scientists & engineers that can drive "bottom-up" projects to execute this strategy successfully.

→ **Working in industry usually means:**

- More flexible resources (increasing resouces with larger and more successful companies)
- Less personal control (resource allocation driven by company imperatives)
- Clear goals (that are defined at least every year and can often change !)

What about……scientific “freedom” ?

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- **Claim**: “…in industry you are <u>not</u> free to do whatever you want, it’s management that decides….”

- **My view:** “Industrial freedom”: To advance company interests, you are *truly* free to pursue whatever path is deemed to be best use of resources to achieve technical and product goals:
  - Shift resources easily between projects.
  - Abandon projects at will if unfruitful.
  - Pursue new projects and (if you can convince management)….. get “instant” funding
  - Resources are proportional to importance of project to company / division
- …with available resources, can pursue any path deemed of company interest (short or long term) – <u>regardless of scientific trends or research funding politics</u>.

- But indeed… you generally do not have complete “freedom” to pursue (full-time) any topic of interest to you…. That is the compromise ☺.

The meaning of R&D: innovation

- **In traditional academic research, the emphasis is often on:**

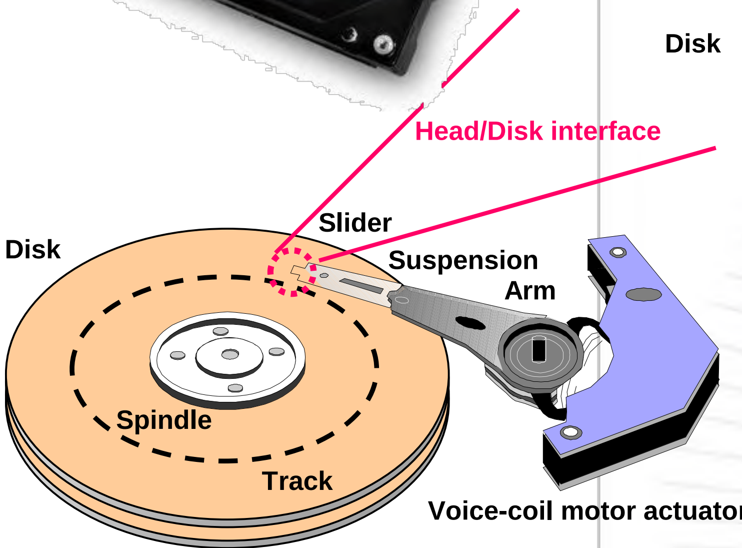
 "new" or "sexy" or even "breakthrough" novel results, with the possibility of publication in the most prestigious journals, invited talks and numerous citations.
… applications are usually considered, but at a somewhat speculative level.

- **In industrial R&D, the most valuable (innovative) results for a company are:**

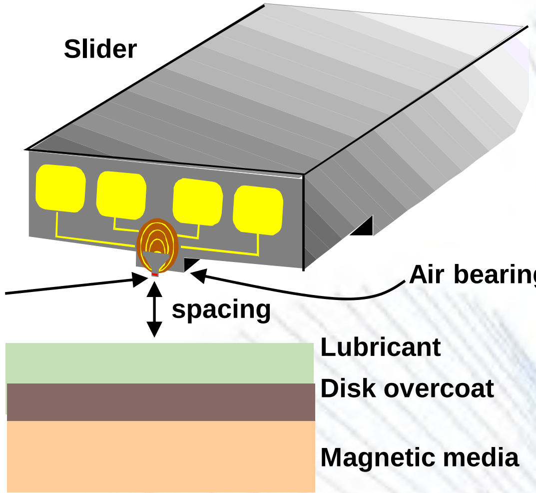
- New technology that will impact company's products and competitiveness
- Improvement and implementation of existing technology:
  - Optimized materials
  - Robust and manufacturable design
- Solving difficult problems that impede product implementation
  - Processing and fabrication technology
  - Scaling of size or performance
  - Performance over practical temperature ranges
  - Reliability and manufacturing yield

- My message: The technical difficulty and scientific depth required to solve above challenges **can be as satisfying and challenging** as "basic research" academic science projects.

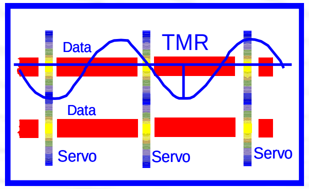
What's in the HDD ?

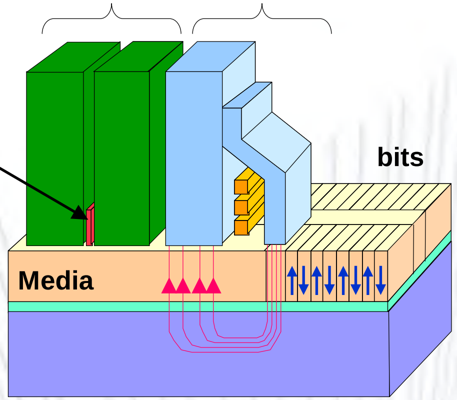


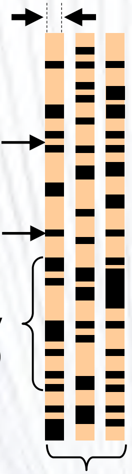
Magnetic recording system



Positioning System





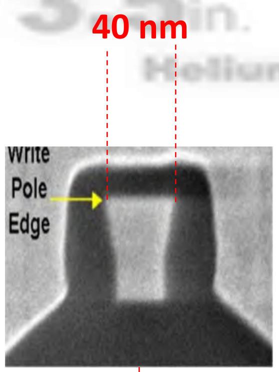


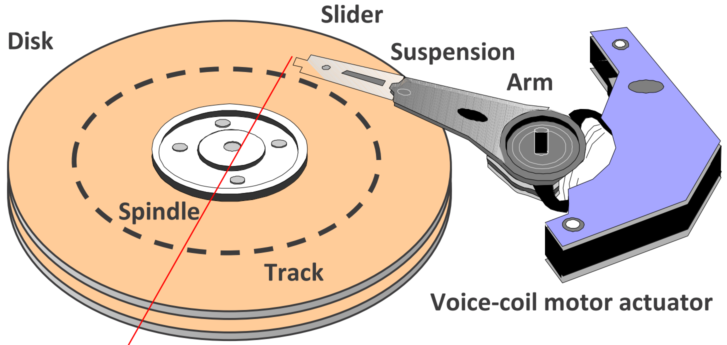
Areal Density
= kbpi x ktpi
= Giga-bit/in²

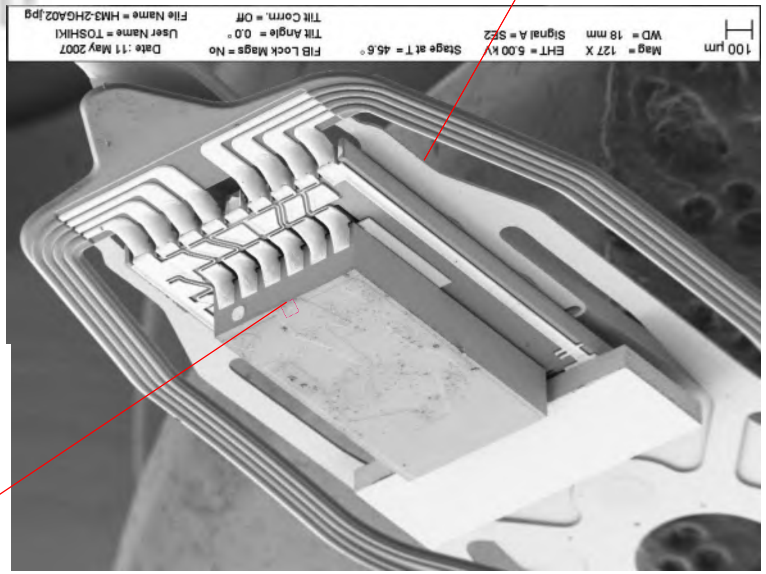
Typical is 2 disks & 4 heads for laptop-HDD

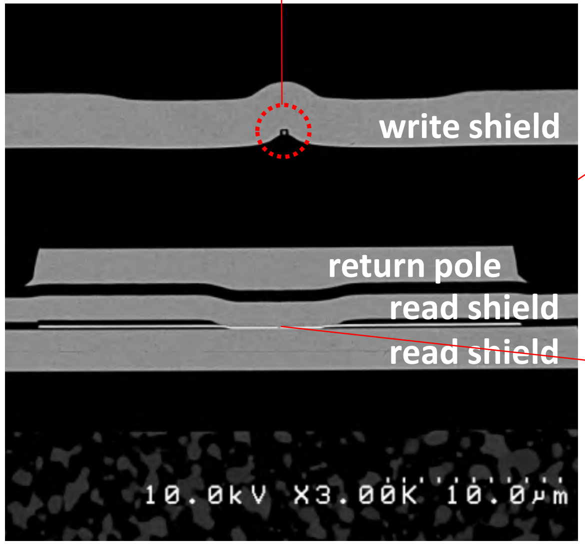
© 2013 HGST, a Western Digital company

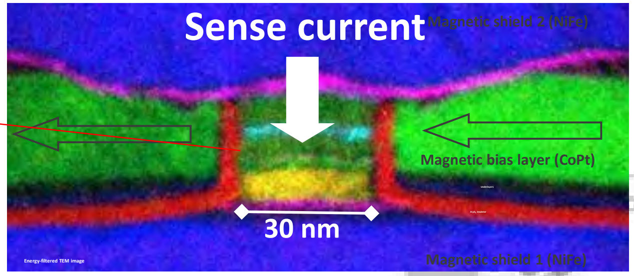
Some pictures





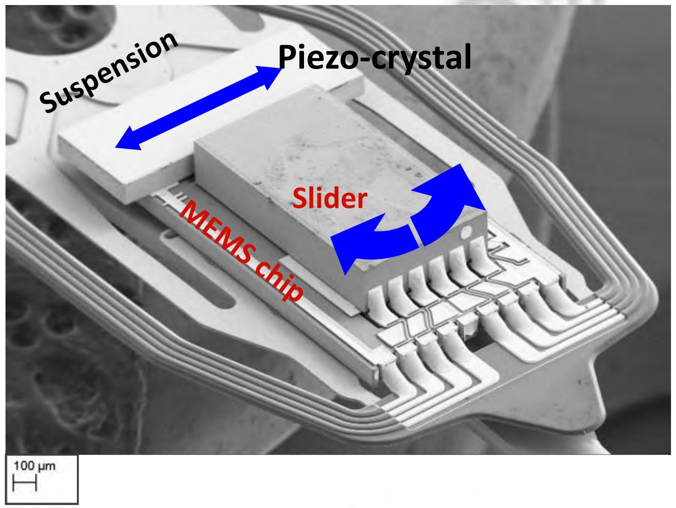




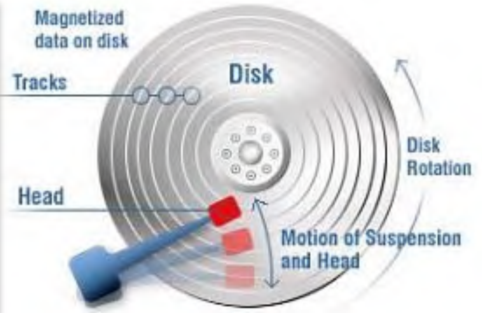


Advanced technologies for accuracy and reliability

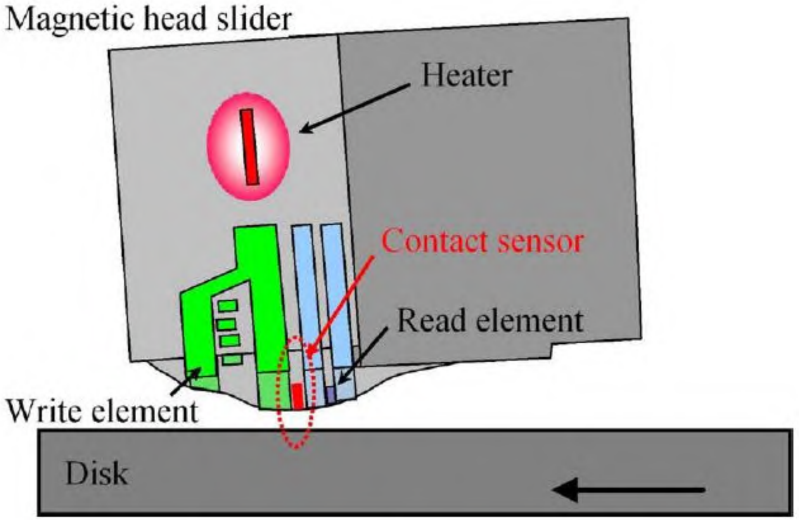
Micro-actuator



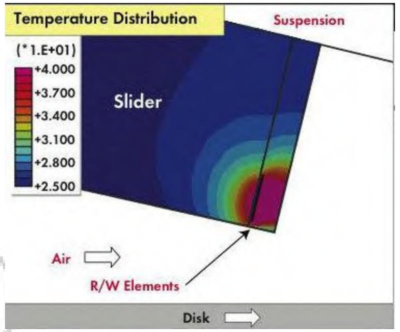
Adjusts angle of flying head to maintain proper angle with respect to tracks



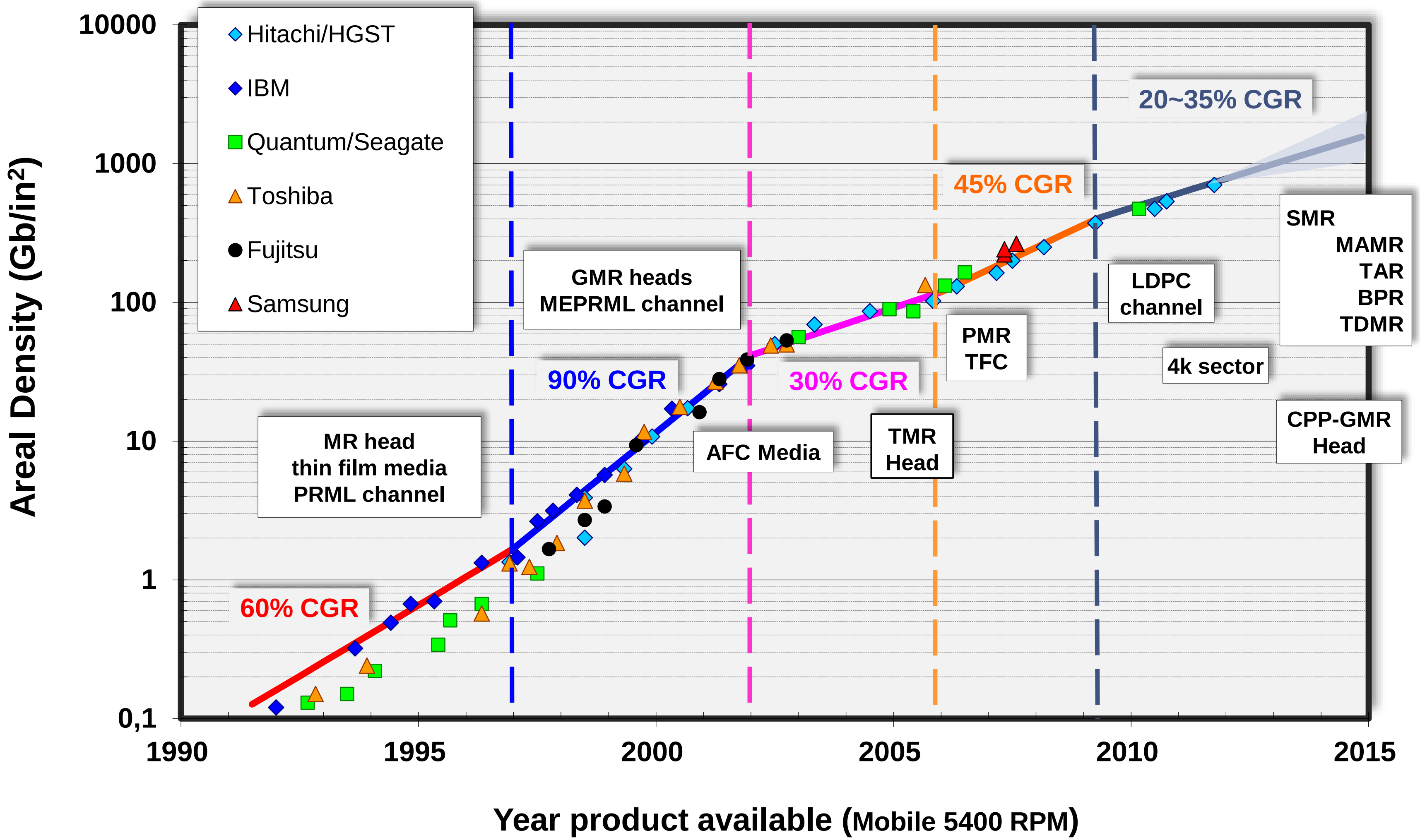
Thermal fly-height control & contact sensing



Use thermal expansion to precisely adjust distance between read/write head and media (performance & reliability)

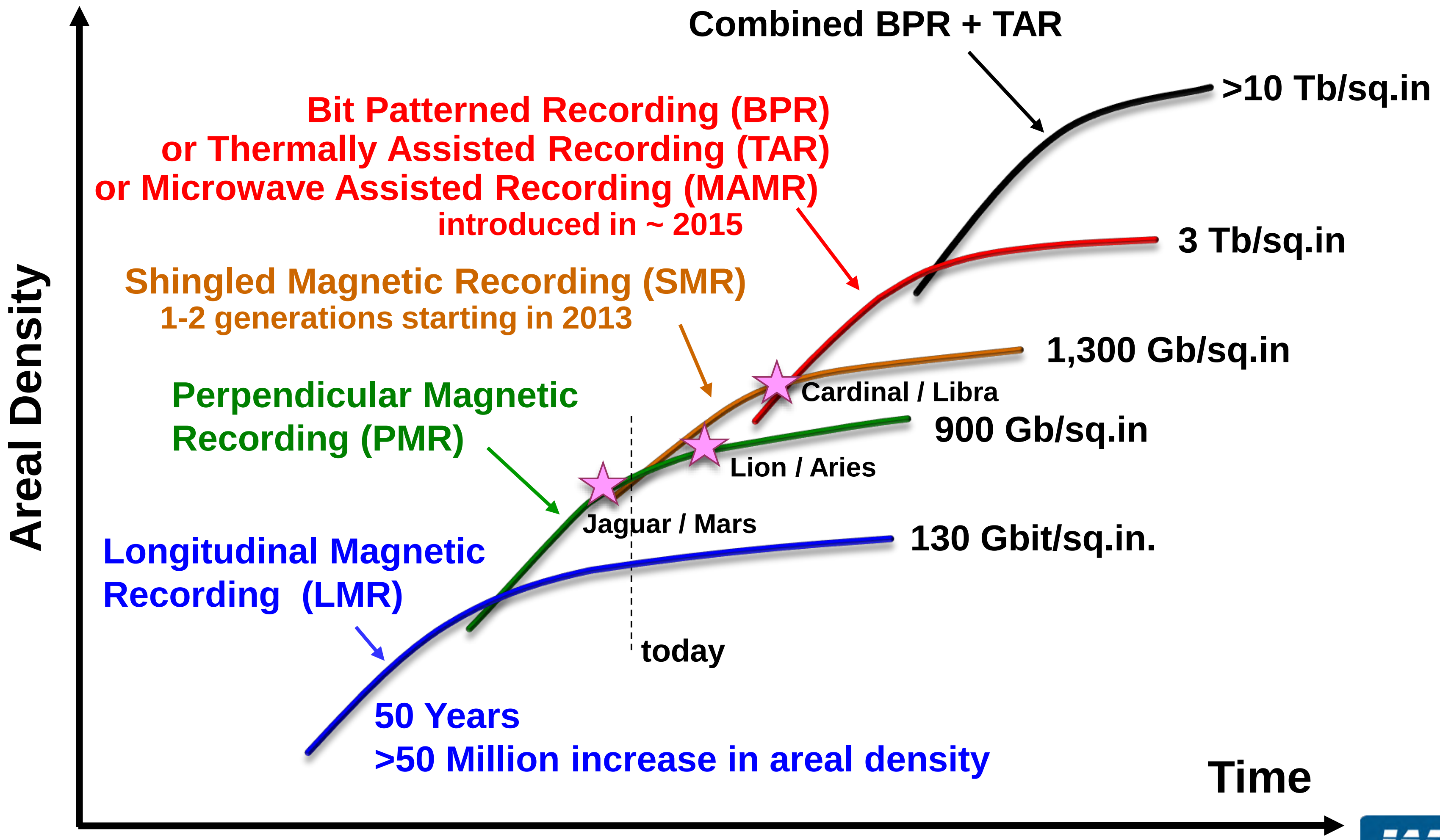


Areal Density Historical Trend



Future Recording Technologies

Several candidates for new technologies to extend beyond 1 Tb/in^2



Publish or Perish ?

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There are numerous technical outlets besides "classical" scientific publications:

➢ In industry, **the goal of scientific work** can be:

- **Basic science results** to demonstrate technical feasibility of potential products.
- **Demonstration project** that inspire a new feature or product
- **Demonstration of technical limitations** of a concept or technology
- **The data needed to validate** a proposed project
  - Modeling
  - Materials evaluation
  - Test device output (including device yield predictions)
- **Solutions to specific blocking issue or complex requirement** arising in devpt or manufacturing.
- **Statistical measurement & analysis** that illuminate "hidden" product development or manufacturing issues.
- **Illuminating complex physics and chemistry** behind "lifetime" product performance and reliability.
- **Invention** disclosures & patents related to product concepts or improvements (next slide).

➢ **Publishing external scientific papers** can be encouraged to:

- Stimulate the field and generate external interest (and therefore external research)
- Disclose technical content to protect freedom of action (vs. patents)
- Bring prestige to company for recruiting purposes

Invention

- Invention disclosures are a big part of potential technical output
  - Protect intellectual property
  - Preserve “freedom of action”
  - Cross-license with other competitor companies
- Large companies typically get awarded *hundreds* of new patents per year
- Inventors get paid small award for filed patent applications and issued patents --- but companies own the inventions
- Major inventions might get recognized with special awards
- New patent law is “first to file” (instead of “first to invent”) → pressure to rapidly patent in competitive industries

Patents
A patent is an agreement between the inventor and the government. The inventor agrees to disclose the idea to the public so that others can learn from it and improve upon it. In exchange, the government agrees to give the inventor the monopoly right to preclude the public from making, using, or selling the invention for a period of 20 years from the date of patent application filing in the U.S.

Trade Secrets (Know How)
A trade secret is any valuable business information that is not generally known and is subject to reasonable efforts to preserve its confidentiality. A trade secret will be protected from misappropriation by those who either obtain access through improper means or who breach a promise to keep the information confidential. A trade secret can last forever, but vanishes the moment the secret is divulged or discovered.

Corporate environment & diversity

- Most businesses promote **equal employment opportunities**.
- Intent to hire the **best-qualified candidates** for opportunities within the company, regardless of race, color, religion, sex, sexual orientation, national origin, age, disability, etc.…
- Diverse hiring is **beneficial to non-traditional career paths**.
- If successful, result is **very diverse team (both professionally and personally)** which ideally reflects community diversity.
- **Welcoming to women** (Flexible schedule, work/life balance , maternity and family leaves).
- No tolerance for any form of **harassment** (anything less is severe risk for company).
- **Management is usually well trained** in promoting diversity, handling harassment, and providing feedback (part of company quality requirements and culture).

How to get a job as a student/postdoc: make yourself be noticed

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- **Become very good at something** (typically you are first hired for a specific expertise).
  - Materials synthesis / Materials analysis
  - Nanofabrication & wafer processing
  - Modeling / Device design
  - Device characterization & test.
  - Programing & software
- **Network at conferences** (there are often many attendees from companies who do not present papers…. Find them !)
  - Look out for advertisement on Job boards or other locations – if interested try to meet someone from the company at Conference.
  - Talk with industrial speakers or poster presenters, or poster visitors (whether you are a poster presenter or just looking at the same poster).
  - Show enthusiasm for your topic & your work – not just for getting a job.
  - Follow-up quickly after the conference if given the opportunity.
- **Work with a company through your thesis advisor** (if available)
  - Make samples for company to measure
  - Measure company's samples
  - Spend a summer internship at company (help on internal project, or bring something new from University)
  - Co-op opportunities (longer term)
- **Traditional Job fairs / Online Job postings**
  - Emphasize your accomplishment and **your enthusiasm** for what you are doing
  - **Companies expect to train**: just want bright and enthusiastic new employees.
  - **Take risks !** You never know how things will turn out – follow what sounds most exciting to you.
  - Apply online…. but try to find out name of & contact hiring manager directly (through insider contacts or by contacting hr dept.).

Jobs: Technology Development vs. Basic Research

- **Cannot limit yourself to “Basic Research” jobs**
- Company have a lot of **opportunities in “Devpt” and “Manufacturing”** that involve very interesting and satisfying technical work:
  - multi-million-dollar top-of-the-line tooling
  - Performance testing
  - Reliability testing
  - Failure analysis
  - Incremental optimization of performance for future products
- **Development & Manufacturing have far more jobs** than Research !
- **Industrial scientific & technical work is teamwork** – lots of people in company will care about & depend on your performance.
  - **Technical employees**
    - Research (Ph.D’s)
    - Engineering (Masters, Ph.D’s)
    - Development (Masters, Ph.D’s)
    - Manufacturing (Bachelors, Masters, Ph.D’s)
    - Technical support of above (Bachelors, Masters)
  - **Technical management** (Job is to formulate goals / organize and enable team / deliver project goals on-time).
    - Former Researchers / Engineers above

Technical hires in large companies

- **Research postdocs**
  - Ph.D's with specialized training or expertize in something the company is interested in
  - A postdoc is a great path towards a job in the company (but not necessarily in Research !!)
- **Research staff**
  - Ph.D.'s or Post-docs with excellent record and recommendations
  - Often hired to staff specific new projects –
- **Devpt / Manuf engineering**
  - Masters, Ph.D's or post-docs with specific skills – but will train.
  - Employees from other companies / competitors – people move !
- **Devpt / manufacturing technical support**
  - Bachelors & Masters with technical aptitude & interest
- **Operators & lower-level technicians**
  - No specific degree requirements – experience, enthusiasm & work ethic are key.

How to decide ?

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- It's <u>not</u> always possible to "decide" on a career.
- If you have options, follow the path that is most attractive to you at each crossroads.
- Don't overthink it – follow your "gut feeling"
- Questions to ask:
  - Will this job make me a better scientist / engineer / teacher/ person ?
  - How will I feel if I <u>don't</u> pursue this opportunity ? (no regrets…)
  - What new opportunities will this job open for me ?

How to stay connected to industry while in academia

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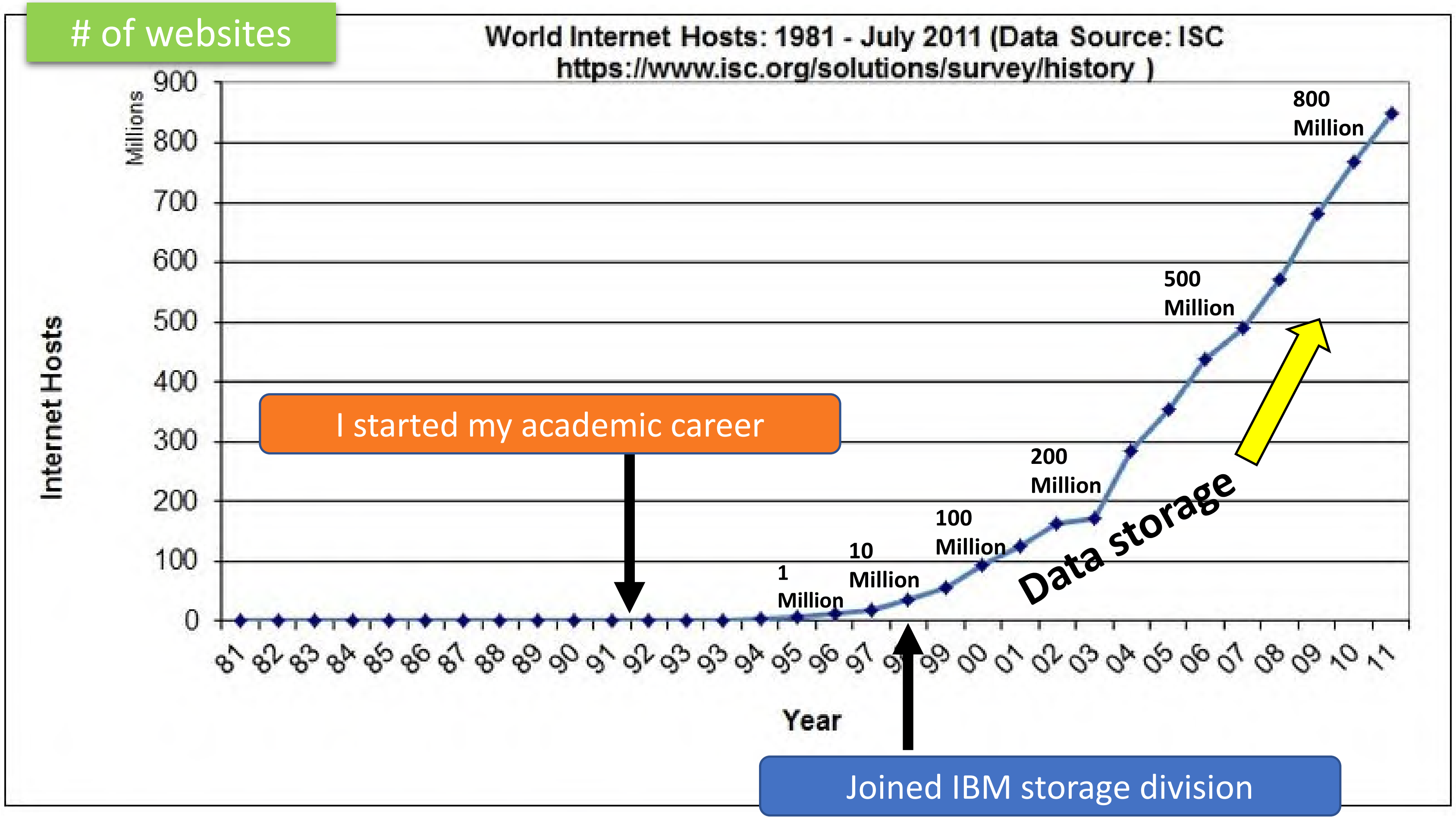
- Network with industrial scientists (conferences)
  - ➢Learn what is (is not) important to them
- Scientific collaborations – offer your unique capabilities
- Visit companies and give talks
- Look for student internships / co-op opportunities
- Participate in industry consortium research (e.g., ASTC – Advanced Storage Technology Consortium research)
- Spend a sabbatical in industry

One more thing…

Look out for big changes… and their consequences ☺



2023 "Technology trends"

1. Computing Power
2. Smarter Devices
3. Datafication
4. Artificial Intelligence and Machine Learning
5. Extended Reality
6. Digital Trust
7. 3D Printing
8. Genomics
9. New Energy Solutions
10. Robotic Process Automation (RPA)
11. Edge Computing
12. Quantum Computing
13. Virtual Reality and Augmented Reality
14. Blockchain
15. Internet of Things (IoT)
16. 5G
17. Cyber Security

Next big changes: Energy transition ? Artificial intelligence ? Robotics ? Bio-engineering ?

Company acquisition → more +++ changes in perspective !!

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Allegro MicroSystems to Acquire Crocus Technology to Accelerate Innovation in TMR Sensing Technology

August 08, 2023

Tunnel Magnetoresistance ("TMR") Represents Fastest Growing Technology in Magnetic Sensing Approaching $1B SAM by 2030

Manchester, N.H., August 8, 2023 – Allegro MicroSystems, Inc. ("Allegro") (Nasdaq: ALGM), a global leader in power and sensing semiconductor technology for motion control and energy efficient systems, today announced that it has signed a definitive agreement to acquire Crocus Technology ("Crocus") for $420 million in cash.

Crocus is a privately held company and a leader in advanced Tunnel Magnetoresistance ("TMR") sensor technology. This acquisition brings unique technology and products well suited to serve high-growth applications in e-Mobility, Clean Energy and Automation, supported by more than 200 patents. The magnetic sensing market is expected to increase to over $5 billion by 2030, with TMR representing the fastest growing segment and expected to approach $1 billion in addressable market by 2030. Automotive and Industrial applications are expected to fuel TMR's estimated 30% CAGR, which significantly exceeds the growth of the overall magnetic sensing market.

"Allegro has invested in TMR technology for the past decade, providing our customers with innovative and high-performing solutions enabling them to design products with optimal performance. We are seeing broader application of TMR technology as the megatrends of Electrification and Automation accelerate. This highly complementary acquisition aligns perfectly with Allegro's growth initiatives and our focus on e-Mobility, Clean Energy and Automation," said Vineet Nargolwala, President and CEO of Allegro. "In addition to accelerating our TMR roadmap and further strengthening our leadership in Magnetic Sensors, the acquisition will allow us to offer a broader and more differentiated product offering to benefit our customers. We also welcome the deep expertise and technical talent that Crocus will add to the Allegro team."

Zack Deiri, President and CEO of Crocus said, "The Crocus team is excited to join Allegro and unite complementary expertise to create superior, highly differentiated customer solutions. By combining Crocus' best-in-class advanced TMR technology with Allegro's long-standing partnerships with leading Automotive and Industrial OEMs and Tier-1's, together, we expect to accelerate adoption of TMR in targeted Automotive and Industrial markets. I am very proud of what Crocus has accomplished and am excited to optimize our TMR technology's full potential together with Allegro."

The planned acquisition of Crocus will be funded with a combination of cash on hand and a new debt issuance. The transaction has been approved by the board of directors of both companies. Subject to customary regulatory approvals and closing conditions, the transaction is expected to close by the end of calendar year 2023. Approval by Allegro's stockholders is not required in connection with the proposed transaction.

Thank you !

Q & A

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Thank You

Intelligence in Sensing™

crocus-technology.com