Physics and hard disk drives- an industrial career perspective

Steven Lambert
APS Industrial Physics Fellow

George Washington University Colloquium
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Outline

1. Brief history- career milestones, my present job
2. Physics careers statistics- where will students work?
3. Why work in industry?
4. Hard disk drive basics- physics at work
   A. Control of head-disk spacing
   B. Tunneling magnetoresistance read heads
   C. The next technology? Heat assisted writing
5. Job prospects and salary statistics
6. Career resources
7. Conclusion
Personal Background

1. PhD in superconductivity and magnetism at UC San Diego.
   A. Made samples, took data, wrote lots of papers

2. 27 years in hard disk drive industry in San Jose, CA
   A. Focus on lab measurements of recording performance for new designs of heads and disks
   B. Six different companies (3 my choice, 3 when company was purchased)
   C. Wide range of topics: limits of magnetic recording, technology development for next-generation products, solving factory problems
   D. Worked with industry consortia including funding and guiding university research

3. Now: Industrial Physics Fellow at American Physical Society
   A. Enhance connection with physicists working in industry
   B. Started Sept 2013 at APS headquarters
   C. Relocated to DC area. Wanted a change, and this qualifies!
Where will physics students work?

1. More than half of physics students have careers in industry!

Douglas Arion, Physics Today, Aug 2013
Companies & Labs employing APS members

1. Many well-known technology companies
2. Note strong showing by defense industry
3. Many members in US DoD labs
4. Remember these are APS members, not all physicists!

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<td>Lab CERN</td>
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50,568 total members

20,091 39.7% Academics
11,217 22.2% Graduate students
6,027 11.9% Govt + Lab
5,692 11.3% retired (US only)
4,530 9.0% Undergrads
3,011 6.0% Company
1,912 3.8% unspecified

Note- data from June 2014
So why work in industry?

In big companies where I worked:
1. Endless stream of interesting problems
   A. Fundamental limitations, factory issues, new products
   B. Physicists are valued for our approach to solving problems
2. Lots of smart people to collaborate with
3. Can usually find a way to publish at least some aspects of your work
   A. But typically not a job requirement
4. Participate in conferences and meet colleagues from competitors
5. Good pay (more on this later)
6. Something you worked on may actually ship in a product

Personal choices
1. I had no burning passion to pursue a particular research path
2. I wanted to do something different from my thesis
   A. Often hired for your skills, not specific knowledge
Some disadvantages of industry

1. Many topics never understood at fundamental level
   A. Learn enough to solve the problem and move on
   B. Downside of “endless stream of interesting problems”

2. Less freedom to pursue your own interests
   A. The work you do must support the company’s business
   B. But academic research may be constrained by funding

3. Product development is hard
   A. Much more than a new idea and initial demonstration
   B. Must evaluate manufacturability, yield, reliability, cost, . . .

4. Can spend a lot of time in meetings
   A. Sharing information is an essential skill. Inform management, colleagues, and internal customers
   B. Must also get input to keep your work aligned with others

5. Bureaucratic churn and company politics
   A. But politics and committees are also present in academia!
Hard disk drive basics

Head moves across disk to access different tracks

Disk is smooth. Tracks defined by magnetic patterns only, not grooves

Magnetic Co-alloy film on glass or aluminum disk

Coil on head arm inside actuator magnet controls head position

Motor is built into hub with fluid bearing (no more ball bearings)

“ramp” retains heads off disk when not spinning
Data track on a disk

1. Track width is defined by the write head
2. Bit density along the track is determined by writing frequency
3. To increase disk capacity:
   A. Reliable writing of narrower tracks
   B. Improved sensitivity of reader
   C. A lot of other details!

Areal density =

tracks per inch x bits per inch

Usually both improve with

bits per inch / tracks per inch ~4
Areal density growth = more capacity

1. Innovations allowed fast density growth, but slowing down in recent years

CGR = Compound Growth Rate in % per year

41% per year is the Moore’s Law doubling of semiconductor density every two years
Keys to areal density increase- lots of physics!

Highest areal density shipping today ~700Gb/in²

= 390,000 tracks per inch  x 1,800,000 bits per inch

65nm

14nm

>300 tracks on the edge of a piece of paper!

Track width enablers
1. Lithography
2. Controlled shape of writing pole
3. Tunneling MR heads
4. Positioning control
5. Dual stage actuators
6. Heat-assisted writing

Bits per inch enablers
1. Head-disk spacing <2nm
2. Better SNR disk magnetic layers
3. Smoother, flatter disks
4. Improved decoding electronics
5. Thinner layers on disk
6. Robust, thin protective layers
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Spacing control - Physics #1

1. Read & write data using read/write heads on a large “slider”
   A. Read/write structures lithographically formed on a wafer
   B. Sliders are cut from the wafer and precisely machined
   C. Slider is supported by airflow when the disk spins
   D. Typical spacing at trailing end ~10nm

Dobisz HGST, 2008
HDDscan.com, 2009
1. 10nm spacing isn’t close enough! Want ~1nm
2. Build “heater” into structure and change spacing by thermal expansion

HGST white paper, 2007
Spacing control- Physics #1

1. So why the focus on spacing?
2. Recording physics shows that the signal from a pattern of wavelength $\lambda$ decays exponentially with spacing $d$:
   \[
   \text{signal} \sim e^{-2\pi d/\lambda}
   \]
   $\rightarrow$ closer spacing gives a huge advantage, but must maintain reliability
3. Diagram shows calculation of temperature rise
   A. Higher temperature causes local thermal expansion
   B. During reading and writing, close the gap from 10nm$\rightarrow$~1nm
   C. Requires careful adjustment in the factory!

HGST white paper, 2007
Spacing control - Physics #1

How did physicists contribute to this?

1. Helped diagnose reliability problem due to excess spacing during writing → led to this invention
   A. Included magnetic force microscopy to analyze data patterns

2. Detailed modeling for size, placement, and materials for the heater

3. Materials characterization for thermal expansion response

4. Develop sophisticated diagnostic tools to monitor spacing in a drive (including time-dependent response)

5. Participate in reliability assessments to determine how close can get to disk
   A. Both population testing of drives and detailed characterization of drive components
1. Electrons can tunnel between two conductors separated by an insulator
   A. Quantum mechanics barrier penetration
   B. Classically electrons cannot flow through the insulator

1. Magnetic Tunnel Junction first reported in 1975 (at 4.2K)
Magnetic tunnel junctions – Physics #2

1. Commercialized in 2006 (after 10 years!)
2. Tunneling MagnetoResistive (TMR) read head
   A. Converts magnetic variation on the disk to electrical signals that can be decoded
3. Arrows show alignment of two magnetic layers in TMR
   A. Low resistance when aligned
   B. High resistance when opposite orientation
4. Now shipping in every HDD made today
5. SEM of TMR from disk side of slider
   A. dc current flows from lower shield to upper shield
   B. Electrons tunnel through Al-O insulating barrier
   C. “pinned layer” has fixed magnetization
   D. “Free layer” rotates under action of data on disk
   E. Barrier is ~100nm wide and 1nm thick. Present devices use MgO, not Al-O

Kobayashi, Fujitsu, 2006
Magnetic tunnel junctions – Physics #2

How did physicists contribute to this?
1. Band structure calculations predicted that MgO would be a good barrier material. It is!!
   A. But also great for forming the correct crystal structure, an unexpected benefit
2. Detailed understanding of magnetism to improve sensitivity. Each layer has several sublayers optimized for signal, corrosion, microstructure, reliability, . . .
3. Optimization of magnetic structures using 3D modeling software
4. Assessment of antiferromagnetic pinning layers to achieve sufficient thermal stability
5. Discover and prevent the many ways these delicate structures can be damaged by electrostatic discharge
6. Innumerable experiments + data analysis to find the best performance. Physics background is great for this since we’ve learned to extract meaning from data.
Heat assisted recording - Physics #3

What’s next for HDD technology? Heat assisted recording

1. $H_{\text{coercive}}$ = how much magnetic field is required to switch the magnetization of a material
2. As areal density increases, need to increase $H_C$
3. Big challenge for two reasons
   A. Existing cobalt-alloy disk layers are maxing out on $H_C$
   B. Existing writing heads cannot increase writing field
4. Clever solution - heat up a spot on the disk layer!
   A. Easier to switch materials at higher temperature
   B. Huge challenges
      1. How to integrate the heating mechanism into a recording head?
      2. Develop a new recording layer
1. Cartoon illustrates the concept

2. Actual integration VERY challenging

3. Prototype drives incorporating this technology have been demonstrated in public

4. Many remaining issues include:
   A. Delivering energy in a small spot onto the recording layer
   B. Aligning laser on “slider”
   C. Developing media with required characteristics
   D. Reliability when locally heading disk surface to >~400°C
Heat assisted recording - Physics #3

Modeling of thermal response:

1. Slider bulges downward when laser is on
   A. NFT is Near Field Transducer that concentrates energy into small spot
2. Disk bulges upward in region around laser spot!

Schreck, HGST, 2014
Heat assisted recording - Physics #3

How do physicists contribute to this?

1. Participate in teams optimizing head and disk designs
2. Design heat delivery system using surface plasmons excited by the laser
   A. Spot size $\sim 50\text{nm} \ll \text{diffraction limit}$
3. Measure thermal response of disk layers using pump-probe laser techniques
4. Detailed modeling of recording process to aid data interpretation and to improve characterization methods
5. Analysis of thermal protrusion including time constants
   A. Develop new methods to study impact on recording
6. Data acquisition and analysis using both components and completed drives
Job opportunities and salary outlook

1. Job opportunities with MS & Bachelors physics degrees
2. Salary outlook for all degree types
3. APS Career resources

4. Data compiled by
   A. AIP Statistical Research Center
   B. National Association of Colleges and Employers

5. Thanks to Crystal Bailey who provided these slides
   A. Manages Careers Program at APS
What about the non-PhD physicists?

According to the AIP Statistical Research Center, 86% of physics bachelors will not earn a Physics PhD.

- Roughly one-third to one-half of Physics Bachelors will go straight into the workforce, mostly in STEM fields.
- Another third will go into graduate study in Physics and Astronomy.
- And the remainder will go into graduate study in other fields—including finance, law, and Medical Physics.

What types of employment are possible for these degree paths?
Initial Employment Sectors of Physics Bachelor’s, Classes of 2009 & 2010 Combined

- Private Sector 53%
- Active Military 8%
- Civilian Gov’t, National Lab 10%
- High School 11%
- College & University 13%
- Other 5%

Physics Bachelors in 2009-10 found initial employment in a variety of areas.

Over half of physics bachelor’s degree recipients in 2009-2010 found work in the private sector.
Master’s Degrees

Between 2006-2008, 64% of physics masters recipients entered or remained in the workforce.

- High School teachers taught Physics, Chemistry and Math
- Salaries for those continuing employment after earning their MS were $13,000 more than new hires.

- Typical titles include lab coordinator, instructor, and lecturer.
- Median Starting Salary: $35,000

- Positions mostly at National Labs, Armed Service Branches, or Trademark Office
- Median Starting Salary: $57,000

- Almost entirely STEM occupations
- Mostly management-level positions
- Median Starting Salary: $62,400

Private Sector 49%

College/University 21%

High School 13%

Other 9%

Civilian Government 9%
In fact...

A physics bachelor’s degree now ranks higher in starting salary than many other technical fields (including mechanical engineering).

The typical starting salary for a physics bachelor degree has increased by nearly $10,000 since 2003.
Not surprisingly, physics master’s degree holders also earn more than physics bachelor’s:

A physics master’s degree will open the door to more advanced positions in a variety of technical fields, with higher salaries.

Note: Typical salaries are the middle 50%, i.e. between the 25th and 75th percentiles. STEM refers to positions in Science, Technology, Engineering and Math.

AIP Statistical Research Center, Initial Employment Survey
Not only does the private sector provide the largest number of jobs for physics PhDs, it also provides the highest-paying jobs, with a starting salary of $90K.

By comparison, average typical starting salaries at Universities and 4-year colleges is around $50K…

…and a University postdoc position typically offers between $40K and $50K.

So, the private sector also offers well-paying employment to Physics PhDs.

http://alp.org/statistics
Physics Workforce: Summary

- Faculty positions are NOT the most common career path for physicists!
- Industry is the largest employment base for Physics PhDs…
  …and for Physics Masters
  ….and Physics Bachelors.

Your career path most likely will not be a straight line…

…BUT! Smart planning requires being aware of—and prepared for—all possibilities.

APS has many career resources to help you with this process
APS Careers Website

• Library of Physicist Profiles
  – Advice from physicists representing a diversity of degree paths and careers

• Job Prospects Pages
  – Profiles feature the most common career paths for physicists.
  – Include descriptions of day to day activities, additional skills and training needed, salary information, job outlooks, and links to other relevant resources

• Physics Employment and Salary Information
  – Clearing house for most recent physics employment data from AIP SRC
  – Thumbnails and links to full reports for more information

• APS Webinars Archive
  – On-demand viewing for all webinar presentations
Watch This Webinar

• Putting your Science to Work with celebrated author and science career coach Peter Fiske.
• Based off of Peter’s popular career workshop at APS March Annual Meetings.
• Webinar covers career planning, interviewing, building your network, and more!
• Archived and freely available to APS members.

Please note: You will need to enter your APS Web ID to access the video

http://go.aps.org/apswebinars

Not an APS member? 1st year free for students
After that annual fee $25 undergrad, $36 graduate (link)
Shared database (Physics Today, IEEE Computing, AVS, and others) means that there are hundreds of jobs available on the site right now.

Job Seekers can:

• Search for jobs on the Job Center (totally free).
• Store your resume, cover letters, and other materials in your profile on the site.
• Apply for positions directly through the Job Center.

Panels and Networking Opportunities at APS Meetings

• Career Workshops
• Recruiting by many companies
• Graduate Student “Lunch with the Experts”
• Career Panel and Networking Reception
APS Local Links

APS Local Links are locally based, grassroots gatherings of students and physicists working in academia, industry, and national labs in a concentrated geographic area.

Local Links groups meet every 4-6 weeks to share ideas, learn about current research in academic, industrial, and national lab settings, build mutually beneficial relationships, and potentially encourage recruitment of students and postdocs into industries.

DC/Baltimore Local Link has launched!

- Most recent meeting on January 22
- Check the website for next event
- Joined the LinkedIn group

http://go.aps.org/local_links
Conclusion

1. Earning a physics degree opens the door to a wide range of job opportunities

2. APS has many career resources to help you through the process of finding a job

3. Working in industry has significant advantages
   - A. Many interesting problems
   - B. Lots of outstanding colleagues
   - C. Excellent salary

4. I enjoyed my 27 years working in industry and would be pleased to answer questions about that experience

   Steven Lambert
   lambert@aps.org