THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
Santa Clara Valley Section

IEEE MAGNETICS

IEEE Magnetics Society

Santa Clara Valley Chapter

Meeting Presentations
November 12th, 2013

Joint Meeting with SCV Technology History Committee

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Presentations

Click on box to jump to presentation

The Evolution Of Thin Film Magnetic Media
Dr. Tu Chen, Former CEO Komag

A Very Brief History of Perpendicular Media Development
Dr. Tom Yamashita, Former CTO Komag

Thin Film Media Ca. 1990
Dr. Tadashi Yogi, Former IBM Technologist

The Evolution of Thin Film Magnetic Media and Its Contribution to the Recent Growth in Information Technology

My Personal Experiences

In Founding Komag Inc.

Tu Chen

BACK

Memoir about my experiences in founding Komag Inc.
Published on-line at Computer History Museum on October 9, 2013.

http://www.computerhistory.org/collections/catalog/102740910

Acknowledgments:

Tom Yamashita, Chris Bajorek, Dag Spicer, Dennis Mee

Reasons for the Book:

- Urging by Denis Mee
- The contribution of Thin Film Media/HDD to explosion of IT Industry
- My recollection of my involvement in Thin Film Media
- Tell how Komag Inc. got started
- Recount the contributions by many people/investment in the Media & Head that led to current HDD

Background: Research memory devices in 1960s

- Permalloy, plated films
- MO
- Bubble

My Start at Xerox PARC - 1971

- Office of the Future project
- $10,000 budget for the computer, $2000 for 300 MB storage.
    - 1971 to 1973: Three Choice- MO, Write Once, Bubble
    - 1973: LCDM (Low Cost Disk Memory) project started
        - Winchester design (IBM 3340) concept, but with 6x recording density
        - Goal: use three-12 inch diameter disk, 100MB each
        - Using plated CoP thin film
        - Team headed by Gordon Hughes, drive to be built by SDS

LCDM Development at PARC

Plated media technology – background

- Ampex – video recorder
- NCR – work by Fisher's group
- IBM – Judge, Morrison, Speliotis – Achieved >800 Oe by Ni addition to CoP.
- SDS 24 inches Disk Head per Track Drive in Production

1975 –30 Prototype drives built with Plated CoP media

- Concern raised over corrosion resistance of the media
- Project discarded in 1979 because of IBM 3370 introduction

1976 – started to also work on sputtered thin film media

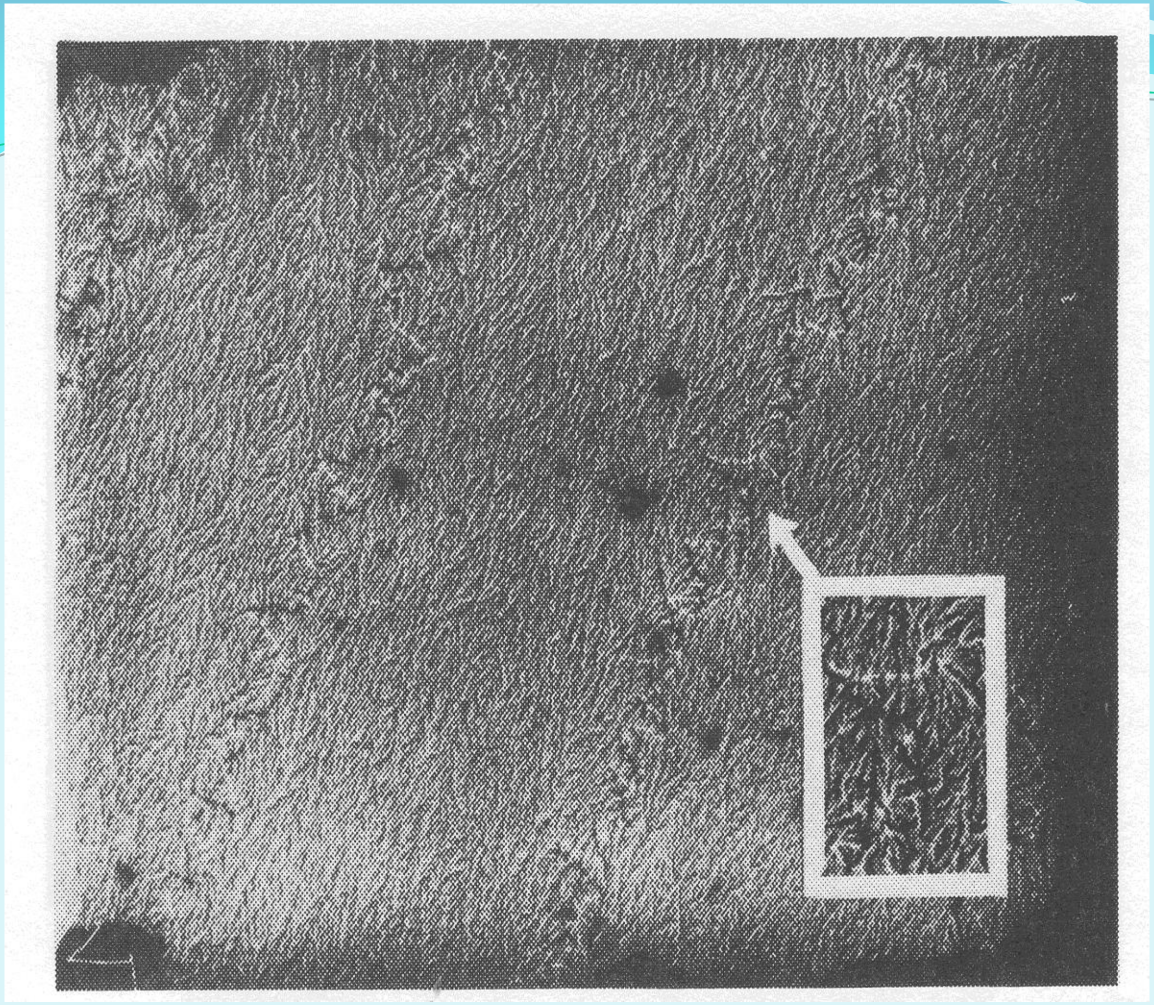
- Obtained $25K budget to re-build a tool used in MO project.
- Address following issues with plated media.
  - Improve corrosion resistance through magnetic alloys and overcoat (silica and vitreous carbon).
  - Ability to raise Hc by using Pt, Re alloying elements
  - Greater control over microstructure/particle isolation

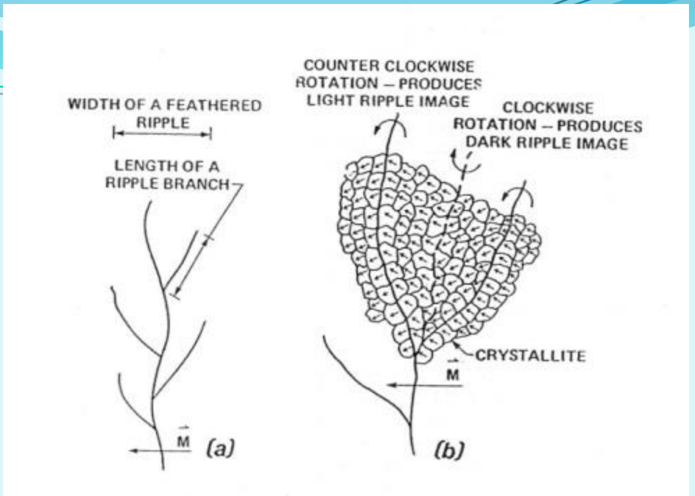
Discovery of Inter-particle exchange interaction in 1975

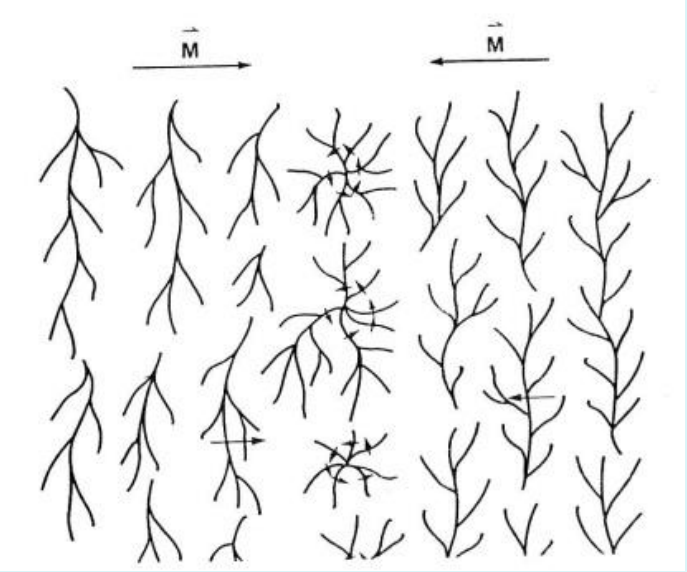
Why: **Hc, Resolution, Squareness**

How: **Lorentz microscopy, TEM microstructure analysis on hundreds of samples. Relate them to recording transitions.**

Solution: **Isolate particles**







Lorentz Microscopy

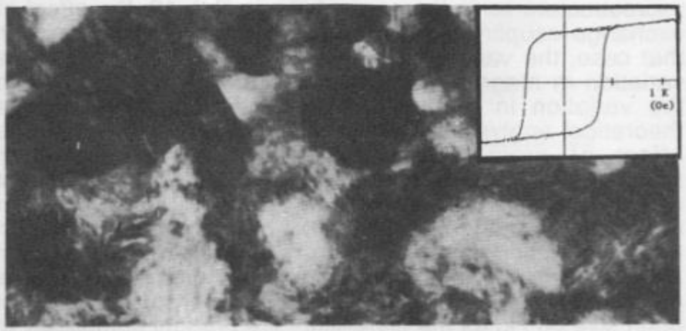


Fig. 6(a) Equiaxial well-packed (B-H loop insert)

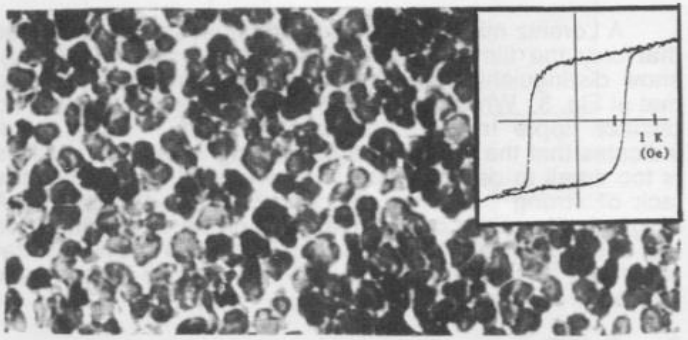


Fig. 6(b) Isolated particles, 50 μ (B-H loop insert)

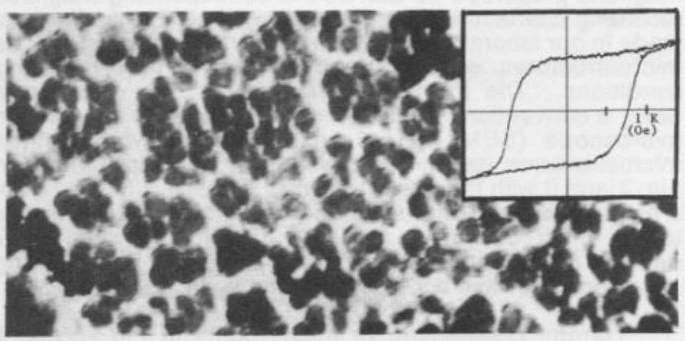


Fig. 6(c) Isolated particles, 70μ (B-H loop insert)

Komag's initial media used high sputtering pressure in order to try to reduce exchange, by physically separating the grains with Ar gas.

Left: Example of films sputtered at 5, 50, and 75 mTorr. As the sputtering pressure is raised, the squareness of the loop degrades. There is corresponding decrease in noise.

Role of interparticle exchange interaction

Presented in 1978, 3M/Intermag conference in Cleveland.

- Gordon Hughes also presented model/simulation showing how exchange interaction affects transition. Results not published formally until 1983.
- 2^{nd} presentation in 1979 Intermag Conf. in NY - invited talk on “The Physical Limit of High Density Recording in Metallic Magnetic Thin Film Media”
  - Probably not many people got it. (solution to the problem was not presented: eg, particle isolation)
  - Neal Bertram understood…… Sent Jimmy Zhu in 1986 – 1987 to work with me on developing his simulation model.

1983- Founding & Funding of Komag

Background:

- Emergence of small form factor 5-¼ inch drive (Seagate) in early 1980’s to support the PC business
- Oxide media from Dysan, Charlton, Nashua
- Ampex Alar, Domain plated media
- New Drive makers: Maxtor, Vertex, Evotek, Miniscribe

Opportunities:

- Tribology issue, black plague or white cloud on slider
- Solve the issue by using all sputtered media process with sputtered carbon overcoat

Komag Approach

- **Magnetics**
  - Copy the characteristics of plated media
  - Not use CoCrX/Cr alloy system
    - Jean P. Lazzari, I. Melnick and Dennis Randet, 1967
    - W.T. Maloney, 1979
  - Use CoPt-based magnetic alloy, based on results by Aboaf's CoPt and Yanagisawa's CoNiPt alloy.
  - RF sputtering for particle isolation and high target utilization
  - Quickly develop inexpensive manufacturing sputter tool

- **Tribology and Reliability**
  - Use sputtered carbon
  - Focus on the effort for solution to the reliability issue

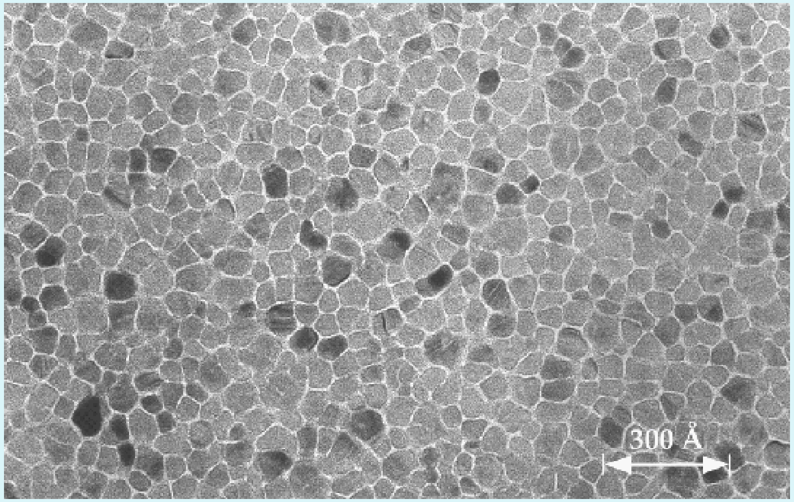
Key Factors to the success of Komag

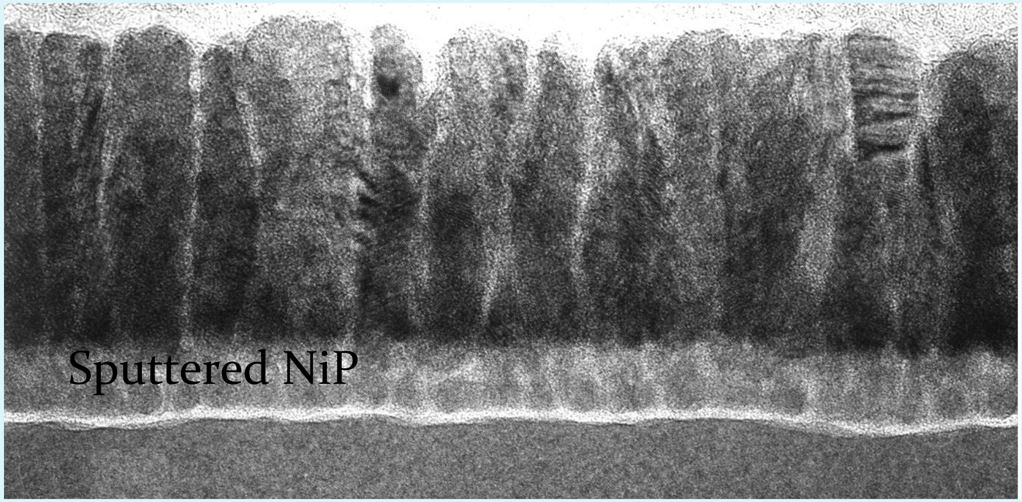
- Exceeded the specification of 20,000 CSS at less than 5 gm load.
  - Jim Shir developed accurate CSS testing tool, which can measure the stiction level during CSS.
  - Finding the polar lube that will work with thin film media (Z-dol and Z-del).
  - Figuring out how to apply the lube (spray & buffed) to the disk.

- Other key parameters for success:
  - CoPtNi- isotropic media, with particle isolation
  - Properly "textured" substrate for stiction control
  - Unique sputtered carbon overcoat

Isotropic media had great success

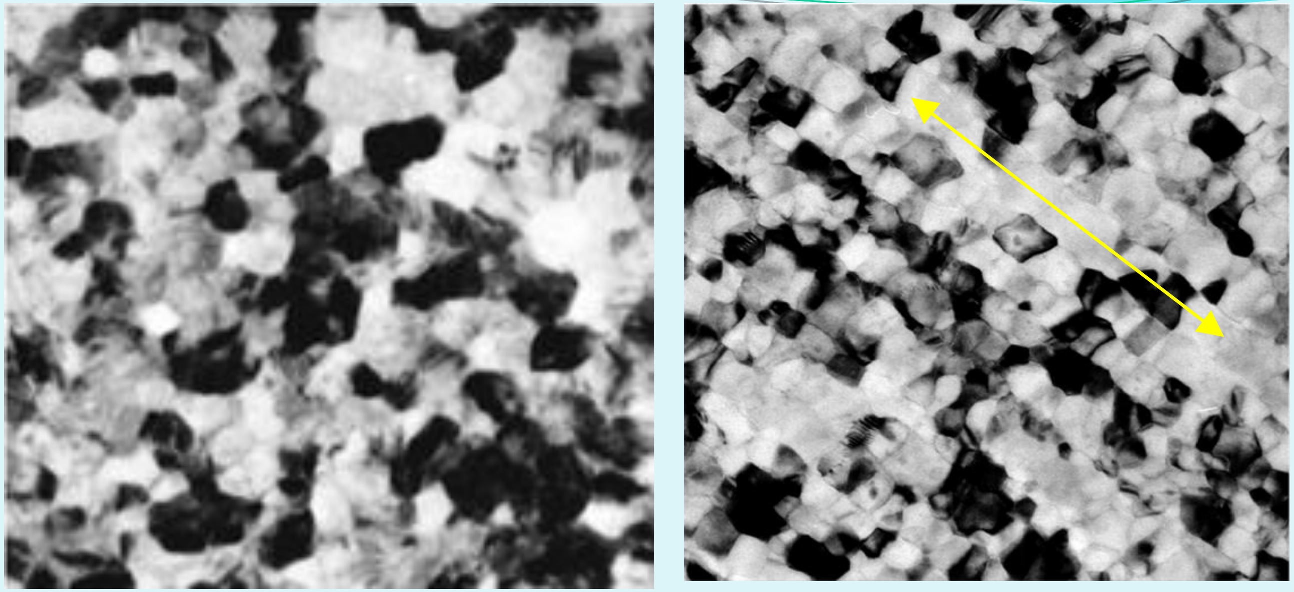
- Large scale in-line sputtering system with moderate vacuum and without the need for substantial heating to make high performance media.
- Tribology performance was superb
- Developed particle isolation method, based on nucleation and growth concept (sputtered NiP underlayer) and later using oxide addition into the magnetic alloy to isolate the grains.





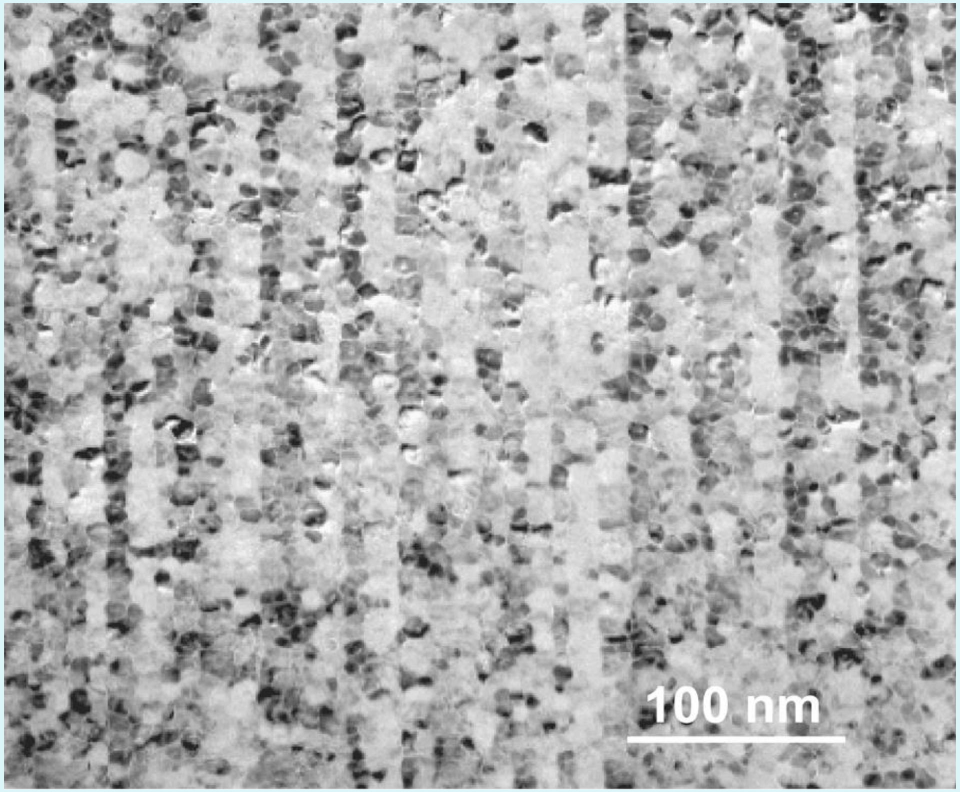
Competition with Oriented Media – 1996

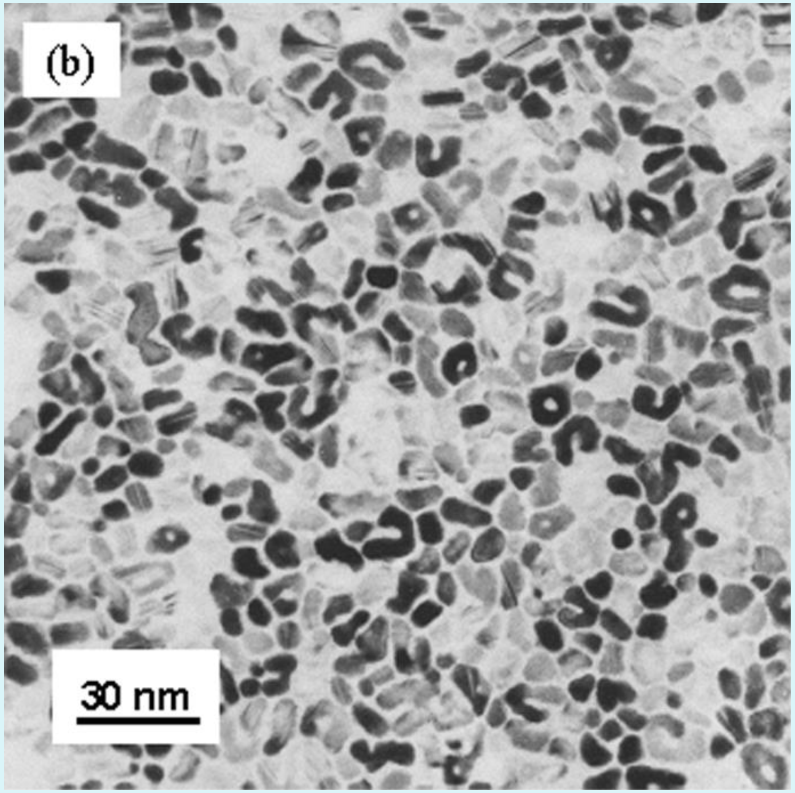
- Use of MR head and narrower tracks gave Oriented Media better advantage over isotropic media.
- Komag had to convert all the systems to make Oriented Media
- Oriented media with Cr underlayer had it's roots in Lazzari's work in 1960's.
- Eltoukhy at IBM discovered the effect in early 1980's.
  - Patented by Hedgcoth afterwards
- Required much better vacuum – not available initially
- Need for good circumferential texture and good vacuum for sputter system prevented it from gaining advantage initially.
- **Discovery of CoCrTa alloy by Fisher et al.** provided the key to its success
  - Required very high substrate heating (~300°C)
  - Cr segregation helped with the particle isolation (and hence its good noise performance) – owes its concept to CoCr alloys used in perpendicular media.
  - We had discovered the Cr segregation effect in CoCr alloy back in 1982 at PARC.



TEM image of $CrMo_{15}$ underlayer of media taken in 2003. Left photo is for un-oriented $CrMo_{15}$ layer on a smooth Aluminum/NiP substrate. Right photo is on a textured substrate showing the alignment of Cr film grains along the texture direction shown by the blue arrow. Also substantial grain refinement as well as shape change can be seen. This change in CrMo grain morphology is part of the phenomenon that leads to magnetic orientation in the media. Grain size is approximately 8 nm, and the film is about 15 nm thick.

Figure courtesy of Gerardo Bertero





Oriented media from Komag showing beautiful grain orientation along the texture lines.

~2003 time-frame 35Gb/in^2 oriented media with Cr and Boron grain boundary segregation.

A <u>Very</u> Brief History of Perpendicular Media Development

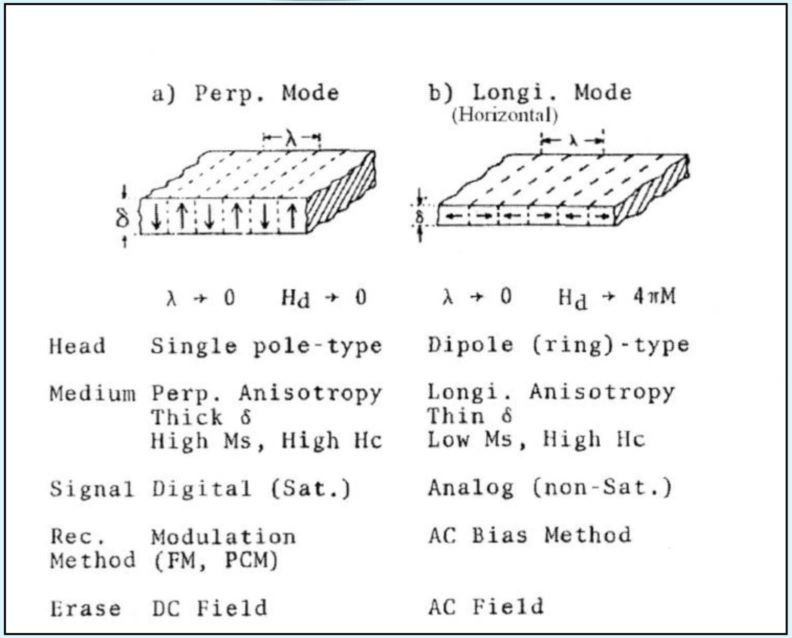
(in 10 minutes)
by
Tom Yamashita

<u>Disclaimer</u>

- Biased view of the history, based on Komag Inc. experience and perspective.
- Based on viewpoints expressed on Tu Chen's Memoir.
- Attempt to link some of the basic concepts developed in early days of longitudinal media (by Tu Chen) and work at Komag Inc. to current perpendicular media design.
- Many contributors to the story (Gerardo Bertero & Team at Komag Inc.)

Early History:

- Shunichi Iwasaki's paper in 1977.
- IBM's efforts in 1955 for RAMAC follow-on was a perpendicular design – ended in failure and forgotten until re-told by Al Hoagland in 2003.
- Many start-ups in early 1980's, AIM, Lanx, Vertimag, all ended in failure.
- Also a major effort by Censtor also ended in failure. Well over $100M+ invested.
- Major effort made in Japan as well, with total investment of perhaps over $1B or more, and nothing came out of it.



Resurrection of PMR

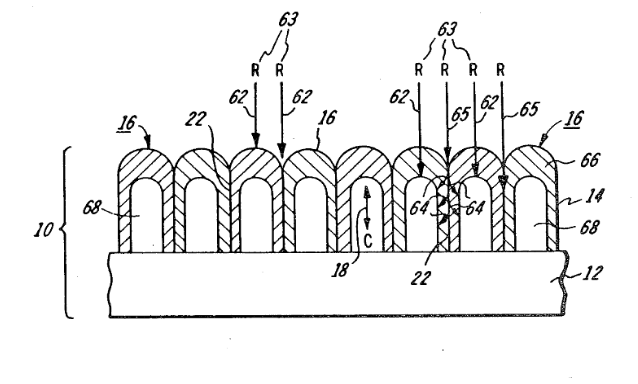
- Industry Consortium played the part (NSIC)
  - ~ 1997, no more gains to be had from GMR heads, AFC media.
  - Small group in NSIC proposed that PMR could solve the issue of thermal stability and extend the areal density. New design roadmap was proposed.
  - SRC in Japan also picked up on the direction (even though SRC was originally founded to specifically counter the undue influence of Iwasaki "mafia" that was always promoting perpendicular recording !)
- HDD industry needed consensus to proceed with perpendicular recording.

Initial Media Design Approaches – was a confusing mess

- Seagate pursued FePt $L1_0$ structure media – at least publically
- HGST was looking to use CoPt multi-layer structure
- Attempt was made to turn existing longitudinal media alloy into perpendicular form (Komag and others).

Key Break-Through

- Toshiba Lab demonstrated a design based on CoPt-Oxide base alloy with Ru underlayer that had high negative Hn nucleation field which solved the noise problem with trying to use existing longitudinal media in perpendicular configuration. Toshiba design had the chance of being manufacturable.
- FePt and Multi-layer structure would not have been manufacturable, at least not easily.
- Toshiba design on oxide based media had it's inspiration on Komag's oxide based isolation scheme used in the isotropic longitudinal media (they told us so !).   Particle isolation is just as important in PMR, if not more difficult because the film thickness are larger.   Tu Chen had experienced considerable difficulties in achieving isolation in perpendicular media due to very large thicknesses involved then (~ 1μm).



From US Patent 4,405,677, "Post Treatment of Perpendicular Magnetic Recording Media", Tu Chen, Sept 20, 1983, shows the schematics of grain isolation by chemical treatment of the grain boundaries

Media Industry still had to solve many difficult issues

- Tribology issues with using carbon overcoat directly on oxide media
- Current design resembles “CGC” (Coupled Granular Continuous) media proposed by Sonobe et al (HGST) in having exchange coupled continuous non-oxide containing alloy on top of the media. This layer helps greatly with the tribology of the carbon overcoat.
- Industry had to re-learn how to make oxide based magnetic target, and how to sputter them without causing major issues (eg, defects).
  - Conversion from Vacuum Induction Melt target process to powder metallurgy-based Hot Press method.
- Managing Ru metal which is very rare and thinly traded.
- Make huge investment in sputter system upgrades to make perpendicular media. More stations were needed, and new cathodes needed to be designed.

- PMR media as it was developed by the industry bears little resemblance to the structure originally proposed by Iwasaki, or worked on by the many start-ups in early 1980’s.
- Professor Iwasaki was awarded the 2010 Japan Prize for his contribution to the development of perpendicular magnetic recording.

Thin Film Media Ca. 1990

Tadashi Yogi, Ph.D.
Data Storage Technologist

November 12, 2013

IEEE Magnetics Society Santa Clara Valley Chapter
Joint Meeting with
SCV Technology History Committee

BACK

Background

- 1984
  - “Optical Recording is going to take over Magnetic Recording”
  - “Perpendicular Recording is going to replace Longitudinal Recording”
  - “There is nothing new under the Sun in Magnetic Recording”

Thin Film Media

- Focus on Magnetics
  - Film Growth
    - Alloying, Underlayer, Sputtering
  - Microstructure
    - TEM, XRD, Thornton Diagram
  - Recording Performance
    - Transition Noise, Resolution, OW
  - Leverage Micro-magnetic Modeling

1 Gb/in2 Demonstration

- Background
  - Thin Film Disk Introduction in IBM product
    - 1988 in Rochester, IBM
  - Extendibility of HDD
    - How far can we push the recording density?
    - When to transition from Longitudinal to Perpendicular?
    - How extendible is Thin Film Disk ?
- Why not push it and see how far we can go?

1 Gb/in2 Demonstration

- Internal Announcement in Oct. 1989
- Intermag presentations in 1990 at Brighton, UK
  - Recording/Head: C. Tsang, M. Chen et al.
  - Media: T. Yogi et al.
  - Channel: T. Howell et al.
- Truly a Team Effort

Afterward

Taking Drives To the Limit

AT I.B.M.'s Almaden Research Center, researchers have multiplied the capacity of Winchester disks twentyfold to squeeze a billion bits of information — a gigabit — onto a square inch. I.B.M. found a way to record data by reorienting magnetic spots on circular tracks a fiftieth the width of human hairs. "We consider it part of our challenge to push up against the limits of conventional technology," said Barry H. Schechtman, the center's manager of storage technology. The new drives might be commercially available by 1995.

I.B.M. is also exploring new ways to expand storage capacity. In the late 1970's, I.B.M. scientists used a laser and thousands of colors to store a thousand bits of data on a microscopic spot. I.B.M. recently took another look at the technology — after learning of Japanese efforts in the same field.

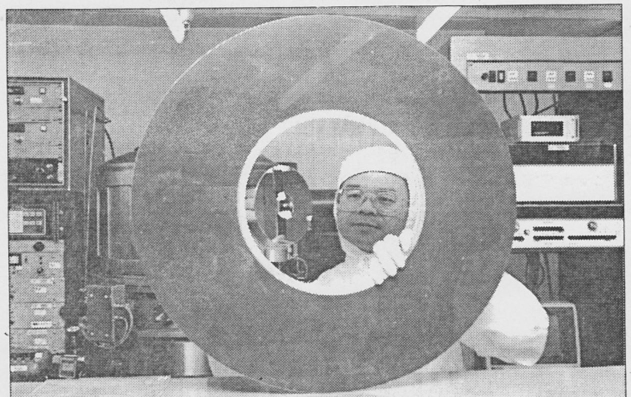
have fallen this year to $4 for a million characters, from about $140 in 1980.

Shorter new product cycles and smaller 3.5-inch and 2.5-inch drives have kept the Japanese off balance. Reliability has increased dramatically. The best drives now average 100,000 hours, or more than 11 years, of constant operation, between failures.

But 1989 saw a shakeout. Conner Peripherals, Maxtor Corporation, Quantum Corporation and Seagate Technology Inc. have exploited new products and markets. But Micropolis Corporation has had large losses, while Miniscribe Corporation and Priam Inc. have sought bankruptcy protection.

Some believe the United States disk-drive industry is still vulnerable to Japanese competition. In May, Quantum filed suit against Sony of Japan, alleging unfair competition, patent infringement and dumping. Sony is the first Japanese disk-drive maker to win a significant share of the United States market, but analysts predict that other Japanese companies will enter, intensifying competition as growth slows. George Scalise, chairman of Maxtor, has suggested a disk-drive research and development consortium to keep the United States ahead of Japan.

Most analysts believe that intense rivalry among United States manufacturers will preserve the industry's lead in the 1990's. "They may be lousy fathers and poor husbands," said James Porter, president of Disk/Trend



The New York Times/Terrence McCarthy

Tadashi Yogi, the I.B.M. researcher who led development of a new 5.25-inch disk, with a 24-inch disk, vintage 1956.

SCV/Magnetics

AROUND THE BAY

Magnetic Recording at 1 Gigabit Per Square Inch

Recent advances in heads, disks, and channels have made it possible to store information through magnetic recording at much higher densities than in current products. In fact, scientists and engineers at the IBM Almaden Research Center in San Jose have set a world record in magnetic data storage by recording a billion bits of information — a gigabit — in just one square inch of a hard disk.

Gigabit storage density is 15 to 30 times the density found on current magnetic disk drives. A billion bits is equivalent to 100,000 double spaced typewritten pages — enough paper to make a stack 33 feet tall, about the height of a three story building.

The Santa Clara Valley Magnetics Society will sponsor a technical meeting on this topic on Tuesday, May 15. The meeting will be held at Le Petit Trianon Restaurant in San Jose, and will feature presentations by three research specialists from the IBM Almaden Research Center, the General Products Division, and the Magnetic Recording Institute in San Jose.

The three co-authors and collaborators in this project are Dr. Ching Tsang, Dr. Tadashi Yogi and Dr. Thomas Howell. They will all three participate at the meeting and will present the technical details of head, disk and signal processing techniques used in recent demonstrations of magnetic recording at areal densities of 1 gigabit/in.².

The details of the magnetoresistive head and design point chosen will be described by Dr. Ching Tsang.

Dr. Tadashi Yogi will discuss the details of the design, and the technical characteristics and performance of the thin film longitudinal media used in the experiments.

Finally, Dr. Thomas Howell will discuss the partial response recording channel and maximum likelihood detection technique used with the high performance heads and disks to achieve measured error rates and off-track performance at areal densities of 1 gigabit per square inch.

All of the critical hardware components for this project were made by conventional manufacturing processes, but it is expected that several years of additional development will be required before gigabit technology can be incorporated into products.

By achieving this record information storage density in their laboratory, the IBM team says that users can expect significant improvements in the magnetic storage capacity of their computers — from laptop to supercomputers — to continue into the next century.

The meeting will be held in the HP Auditorium at 5301 Stevens Creek Blvd., at Lawrence Expressway in Santa Clara. Come early for the coffee and conversation prior to the presentation. See the calendar of events for details.

Dr. Ching Tsang, of IBM Alamden Research Center, is shown placing one of the experimental disks on a precision laboratory test stand used to achieve the gigabit milestone.

7

Aftermath

- Some Comments We Heard
  - “Nice demonstration, but not manufacturable”
  - “Because of the demonstration, we decided to invest”

Projection

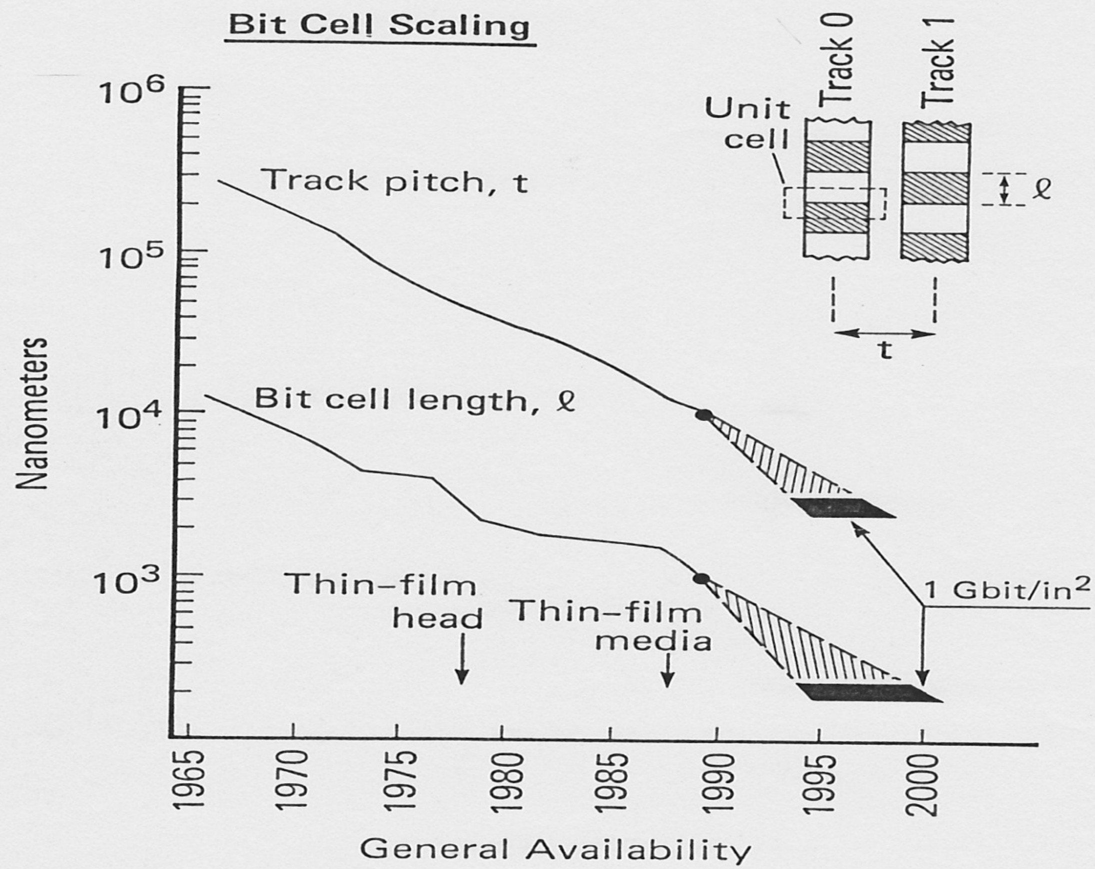


Figure 1. Progress in the track pitch and the bit cell length as a function of the year available for high-end disk file devices (from Reference 1).

Thank you…