EMMC case study: Seagate Technology

Integrated Recording Model for Heat Assisted Magnetic Recording (HAMR)

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Which are your objectives as an industrial consumer of modelling?

- Description of the industrial problem

  The magnetic hard-drive industry has overseen exponential growth in the areal density of recorded information over the past 50 years. As the industry now moves to the next generation of storage densities in the Tb/in2 range it needs new technologies to keep pace with its own roadmap. Current hard drive products have areal densities of about $1Tb/in^2$, and $2Tb/in^2$ products are likely within the next 3 years. The technology required to hit the 5Tb/in2 milestone has not been demonstrated, even experimentally, and requires much fundamental work to ensure products in keeping with the current technology growth rate.

Heat assisted magnetic recording (HAMR) is the front-running technology to ensure sufficient hard drive areal density growth after 2016. HAMR is more efficient as it heats up the location on the disk, where the bit is written, to several hundred degrees °C. The temperature increase improves the ability of the writer to record a bit to the disk, allowing the use of high anisotropy media which results in increased stability and performance. Heat spots on the disk of less than 50nm in dimension are possible if a nanoplasmonic element is used to focus laser light at the bit location.

The nature of the high temperature heating at sub-50nm dimensions in a magnetically dynamic environment means that much system innovation and material development was required even to achieve the first HAMR products.

- Classification of the project:
  - *Material:* FePt and FePt-Fe bilayers, plasmonic and nanophotonic materials
  - Scale of the material phenomena to be described: sub 50 nm.
  - *Industrial application:* Magnetic recording, solid state materials, components and recording head sub-system.
  - *Industrial sector:* Electronics, Magnetic hard-drive industry
  - *Weakness of approach used up until now:* The viability of future hard drive technology depends on the ability of the storage industry to demonstrate and continuously optimise HAMR. This is impossible to achieve economically and efficiently with the current approach of costly and lengthy experimentation, especially due to the increasing complexity of interrelated phenomena.
- Requirements and expected results to understand the material behaviour.

  Modelling should enable the complex interrelationship of phenomena to be investigated. This requires tools that represent high temperature effects with confidence, including accurate temperature and reliability prediction of the recording head as well as Bit Error Rates (BER) characterizing the HAMR recording performance.

How did materials modelling play a key role in problem solving?

Materials modelling supported the design of materials for the magnetic elements and supported the design and optimization of the HAMR recording system. It provided information about the heating of the media during recording, reliability of the recording head, and recording performance. These predictions are essential to successful iteration of the technology towards the final product specification.

(a) Materials Design: The relevant high temperature behaviour of candidate materials (crystal and nanostructures) for the magnetic elements was studied and candidate materials proposed. For example, modelling was able to explain the unusual temperature dependence of the anisotropy of FePt recording layer media [1], which is important for the HAMR process.
(b) HAMR recording head prototyping was achieved by integration of nanoscale simulations of the thermal and magnetic data writing fields with nanoscale magnetic simulation of the disk [2] The modelling provided data on how well the recording head will heat the media to record a bit while also predicting the temperature and reliability of the recording head.
(c) HAMR recording performance – once the heat spot has been determined from the recording head the recording process was modelled to determine if this will lead to successful recording on the HAMR disk. This included determination of the Bit Error Rate (BER), a characteristic of recording performance.

What tools and methodologies have been applied?

- Fundamental material modelling:

    i. Electronic models. In order to predict and provide ideas on materials with improved optical performance and thermal stability fundamental, electronic models (Quantum Density Functional Theory) have been used. Standard plane-wave density functional methods were used for structural optimisation and bulk properties while a fully relativistic DFT approach was required for site-resolved magnetic properties. Note that energies have to be determined to high accuracy since the magnetocrystalline anisotropy energy is generally a small contribution (of the order of meV). These approaches directed the finding of better plasmonic and nanophotonic materials. Once predictions on specific materials were made industrial trials quickly validated the performance benefits of these materials.

    ii. Atomistic models. These are based on classical spin models with Hamiltonians including Heisenberg exchange. Parameters (when possible) were determined using ab-initio calculations; material parameters are site-resolved when appropriate.

- Macroscopic materials and device simulations

    – *Continuum models. These are based on the micromagnetic formalism with a long-wavelength approximation to the magnetic exchange interaction and use numerous sophisticated approaches to the calculation of the magnetostatic field. Areas of application include flux calculations in write head design and development and output from read sensors.*

    – *Mesoscopic models. These are models for grain based on essentially similar physics to the continuum models with the following exceptions; firstly a single spin per grain is assigned and secondly the (rather weak) exchange coupling between the spins is introduced in Heisenberg form with a magnitude proportional to the contact area between the grains. Granular structures are generated using the Voronoi construction which leads to realistic lognormal grain size dispersions. For recording* *simulations the dynamic properties are represented either by the Landau-Lifshitz-Gilbert equation (for conventional perpendicular recording) and the Landau-Lifshitz-Bloch equation for HAMR (where longitudinal fluctuations of the magnetisation are important. In both cases the local field is augmented by a stochastic term representing thermal fluctuations.*

– *External inputs to models. Described above are the essential elements of the magnetic recording/reading simulations. Input to the recording models are simulations of time evolution of the write field and (in the case of HAMR) the temperature. The required electromagnetic and thermal information are currently provided using continuum models using finite element solvers at a scale of a few tens of nanometres.*

- Modelling workflow

Figure 1 shows an outline of the modelling workflow based on transfer of parametric information from electronic structure calculations using ab-initio density functional theory to atomistic calculations and which are then used to calculate the temperature dependent parameters for input to the continuum and mesoscopic models.

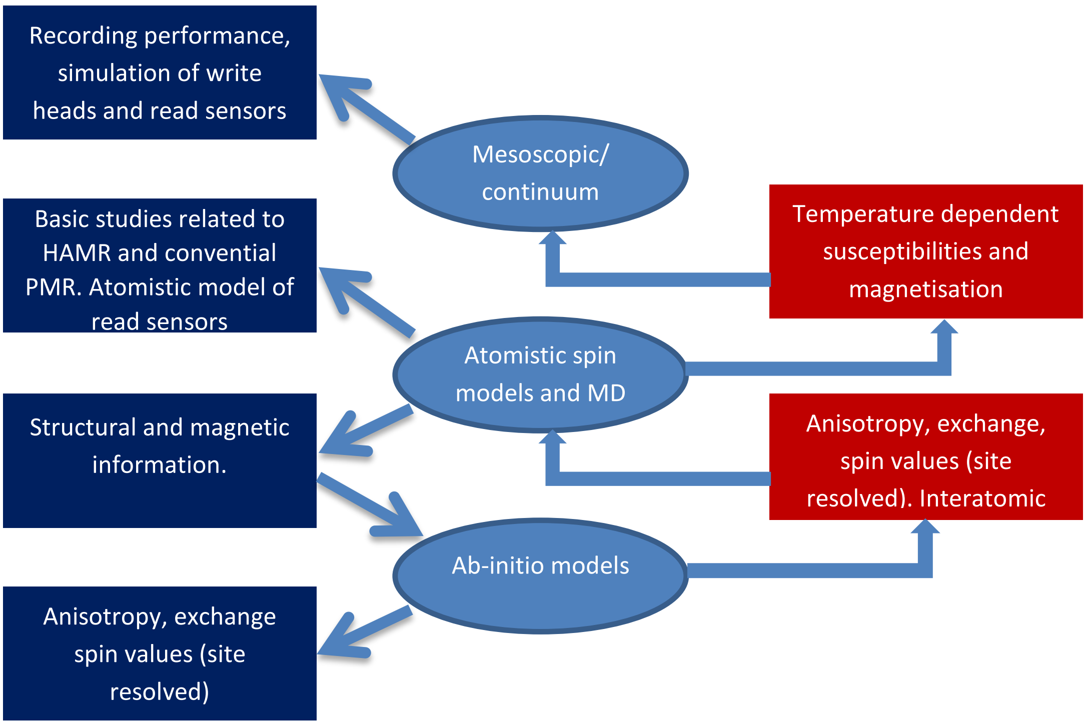

Figure 1: Schematic of the modelling workflow showing the links between the models and indicating the information transferred (right column). Principal usage is shown in the left column.

What investments were made during the project?

For the HAMR development at its Northern Ireland facility Seagate hired 35 people with PhD level qualifications, 12 of which are engaged in modelling. The overall investment in HAMR at the Northern Ireland facility has been €47m (http://www.bbc.co.uk/news/uk-northern-ireland-foyle-west-29736119), including an approximately €4m investment in modelling resources over 4 years.

What was the business impact versus previous approach?

The ability to model recording head reliability is estimated to have saved 6 months in the development time of new HAMR technology and tens of millions of Euro in development costs.

References

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