CHALLENGES AND OPPORTUNITIES IN NANO-MAGNETISM RESEARCH AND TECHNOLOGY

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Nanotechnology is expected to change and shape our lives in the 21st century. It is, however, not just a far out vision, but actually part of our daily lives already. For instance, the computer hard disk drive (HDD), which is found in all Personal Computers and increasingly in consumer electronics applications, is one of the technologies that already requires and utilizes nm-scale precision today [1]. In the last decade alone, the areal recording density has increased by a factor of 100, bringing today's product level bit size down to $(56\,\mathrm{nm})^2$ [2]. To reach this level of recording density, magnetic media grain sizes of only 8 nm diameter and below are required [3]. At this grain size level, thermal fluctuations can be so strong that the magnetic state becomes unstable. This phenomenon is generally referred to as super-paramagnetism and was anticipated to be the "kiss of death" for HDD technology just 10 years ago with an estimated maximum achievable areal density of 36 $\mathrm{Gbit/in}^2$ [4]. However, recent technical advances enabled this technology to circumvent or at least delay these fundamental limits to take hold and are the reason why HDDs with areal densities in excess of 200 $\mathrm{Gbit/in}^2$ are commercially available today [2].

Figure 1 shows on the left hand side a photograph of an opened-up HDD, exposing the disk that carries the magnetic thin film, in which the information is actually stored as a magnetic bit pattern. The entire disk consists hereby of nano-scale grains with an average diameter of only 8 nm and about 15 nm thickness. A Transmission Electron Micrograph (TEM) of such a structure is shown on the left hand side of fig. 2. One can also see very clearly from this TEM picture that the individual grains are separated from each other by a grain boundary zone of only about 1 nm width, which is engineered to be non-magnetic. By creating such a nano-granular structure, each grain can be addressed individually and single grain level resolution can be achieved. While the resolution of such nano-granular magnetic materials is excellent, it comes at a cost in thermal stability because the individual addressability also requires individual stability, i.e. each grain has to be magnetically stable on its own.

The key parameter characterizing the stability of a magnetic grain in a HDD disk is the product of anisotropy energy K and grain volume V. The main media design limitation is that increasing K also raises the magnetic write field necessary to actively reverse the magnetic state of the grain [3]. Thus, simply increasing the material parameter K would make it ultimately impossible to transfer the information into the magnetic recording media in the first place. It is this simultaneous K dependence of writeability and stability that is driving the presently occurring technology shift from longitudinal to perpendicular recording, both of which are schematically shown on the right hand side of fig. 1. Perpendicular recording has a number of thermal stability advantages when compared to longitudinal recording, one of which is the fact that higher magnetic write fields can be achieved allowing for the use of higher K materials as recording media, which in turn can be utilized to create smaller magnetic grains that are thermally stable. This advantage of perpendicular recording is due to the use of a soft magnetic under layer (SUL), which produces a mirror image of the main recording pole, allows to channel the entire head field flux through the magnetically hard recording layer and results in much higher write fields.

Also in recent years, advanced multilayered media structures with an improved writeability to stability ratio have been designed and were successfully deployed as main-stream product technology [5]. Presently, there is a substantial interest in Exchange Spring Layer (ESL)-media (shown schematically in the center of fig.2), which utilize a combination of soft and hard magnetic materials [6]. An improved writeability is hereby achieved through a non-uniform field reversal mode. This functionality, however, requires that the interlayer coupling in such structures is tuned appropriately. Too strong a coupling will prohibit this non-uniform reversal, while a coupling that is too weak will decouple the reversal of the layers altogether [6]. The crucial importance of the interlayer can be seen on the right hand side of fig. 2. Here, the coupling strength between the soft magnetic ESL and the hard magnetic base recording layer (MAG) was tuned by means of varying the thickness of a suitable coupling layer (CL) in the sub-nm regime. A clear writeability optimum, given as a minimum in the required write head current I_{95}, is visible and demonstrates the viability of this media technology for large-scale industrial applications [7].

While these examples demonstrate that ingenuity enables sustained technological progress in the face of looming physical limits, those limits will not disappear. On the contrary, they require a constant flow of novel ideas and substantial research efforts to allow for further advances in this industrial-scale nanotechnology in particular, as well as the Nano-Scienes overall.

References:

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Figures:

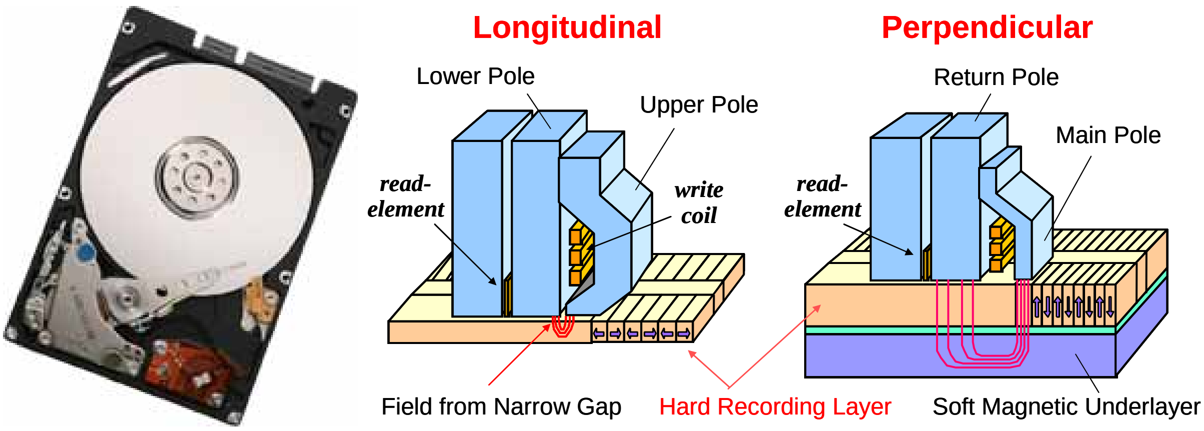

Figure 1:

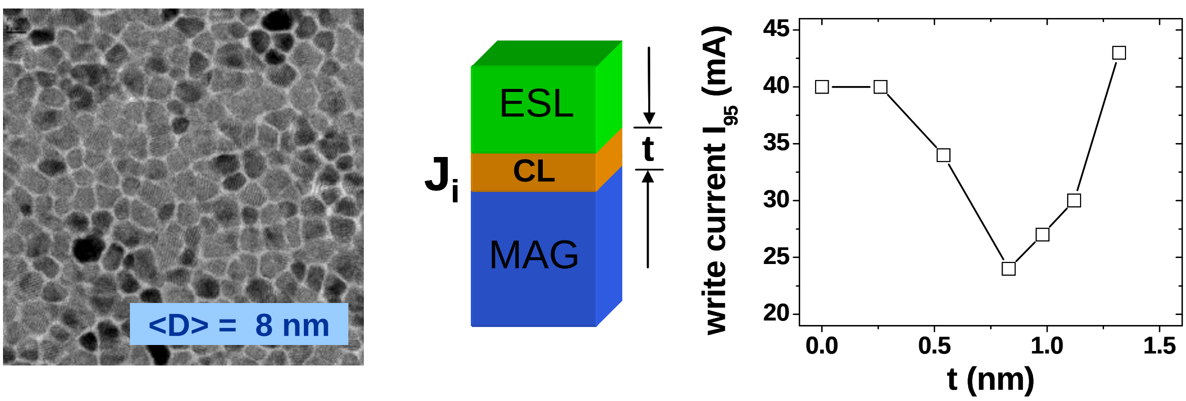

Figure 2: