Response of suspensions of microfabricated magnetic discs to time varying fields

Per A. Löthman[a,b], Tijmen Hageman[a,b], Jordi Hendrix [b], Hans Keizer [b], Henk van Wolferen [b], Kees Ma [b], Melissa van de Loosdrecht [b], Bennie ten Haken [b], Thijs Bolhuis [b], Leon Abelmann [a,b*]

[a] *KIST Europe, Saarbrücken, Germany*
[b] *University of Twente, Enschede, Netherlands*
[*] *Corresponding author, email: l.abelmann@kist-europe.de*

I. Introduction

At IWMPI 2017 we introduced suspensions of microfabricated magnetic discs of 2 µm diameter as alternatives for colloidal suspensions, and showed their response in magnetic particle spectroscopy at 20 kHz [1]. In this contribution we investigated the magnetic stability of these suspensions at longer time scales, and introduce the first sub-micron discs.

II. Material and Methods

The 2 µm diameter discs were prepared from Au(14nm)/NiFe(12nm)/Au(14nm) thin films deposited on a negative photoresist as sacrificial layer by contact mask lithography and ion beam etching [1]. The 200 nm diameter discs were prepared in a similar way, but with laser interference lithography. This technique allows for full-wafer exposure within one minute.

The transmission of light through a suspension was analyzed by means of a LED-photodiode detection system with two orthogonal coils cells to provide a field in the order of one mT (Fig. 1).

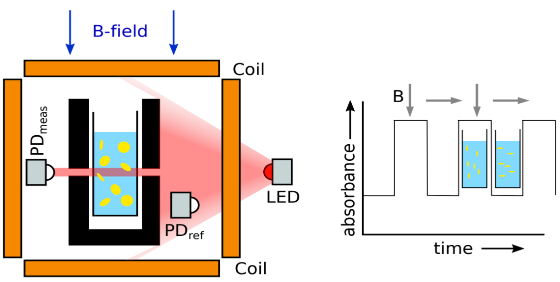


Figure 1: *The transmission of light through a suspension of magnetic discs is analyzed as function of the applied field angle.*

Vibrating sample magnetometry was performed in a Veeco VSM-10 vector coil system on 50 µL of a suspension of 345 discs/nL. The total measurement time for a loop is one to two hours. The magnetic susceptibility was measured by a homebuilt superparamagnetic particle analyzer at a drive field of 0.3 mT at 2.5 kHz [2].

III. Results

There is a remarkable difference in the slow magnetic response of the discs when they are still on the production wafer (black curve in Fig. 1) and when in suspension (red curve). A second step at about 5 mT can be observed. This step is not visible in the susceptibility measurement at 2.5 kHz (Fig. 2). In that measurement a peak develops around 1 mT for drive frequencies above 10 kHz. Strangely, this peak does not coincide with the coercivity of the VSM loop.

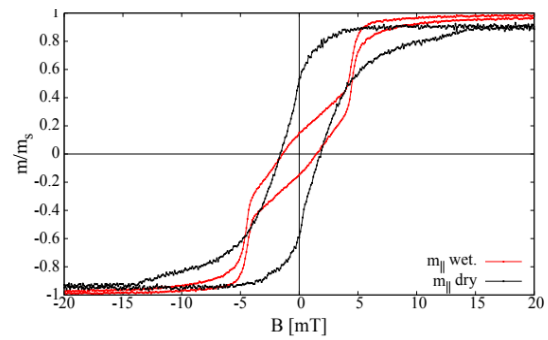


Figure 1: *Magnetic hysteresis loop measured by VSM of a Au/NiFe/Au discs of 2 µm diameter in suspension (red curve) and in dry state (black curve).*

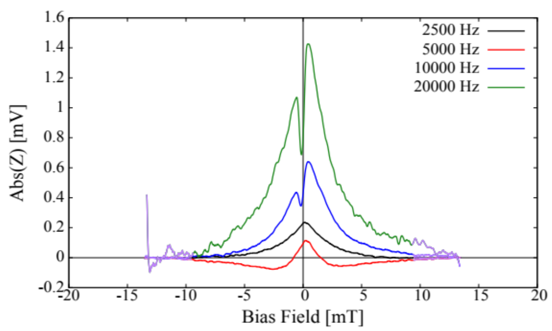


Figure 2: *Magnetic susceptibility of the suspension as a function of bias field for different frequencies.*

We suspect that the low frequency anomaly has an origin in particle chain formation. To further investigate the low frequency behavior, we observed the light transmitted through a suspension of the discs. Fig. 4 shows the transmission as a function of applied field angle. At zero degree, the magnetic field is aligned parallel to the light beam and the transmission of light is maximal. When the field is tilted perpendicular to the light direction, the discs block the light and the signal on the photodiode decreases.

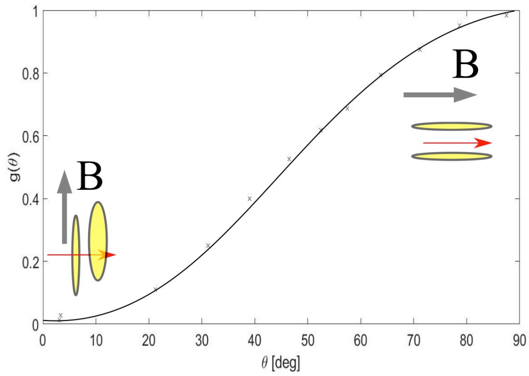


Figure 4: *Absorbance normalized from 0-1 of a suspension of Au/NiFe/Au discs of 2 µm diameter as a function of the applied field angle.*

We rotated the field from parallel to perpendicular every 10 s. After 7 hours, the signal dropped by a factor of two, which can be explained by sedimentation. At the same time however the time constant increases, and the pattern becomes erratic (Fig. 5). We believe this is a clear sign of disc interaction, which could also be the origin of the strange behavior in the VSM loop.

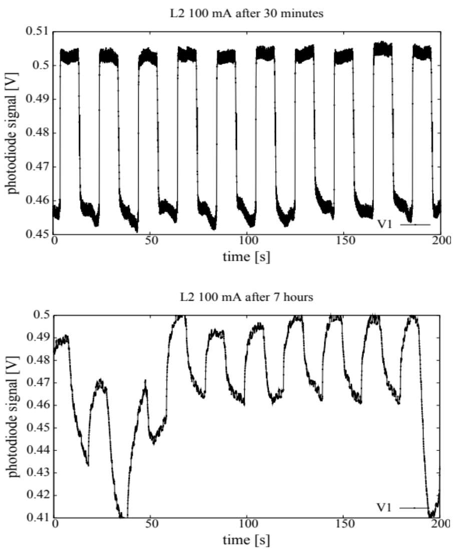
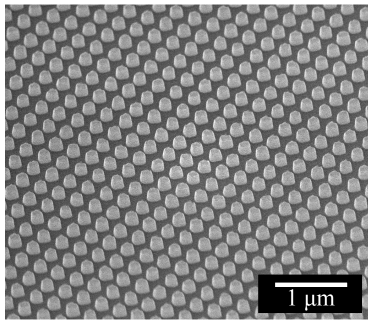


Figure 5: *The response of the suspension changes dramatically over time. Above after 30 min, below after 7 hours.*

Next to the anomalous behavior in liquid, at the conference we will present our first results on magnetic disc of only 200 nm in diameter, prepared by laser interference lithography. Fig. 5 shows the patterned Au/NiFe/Au elements when they are still on the production wafer. The VSM loop shows that at this small size, the hysteresis entirely disappears.



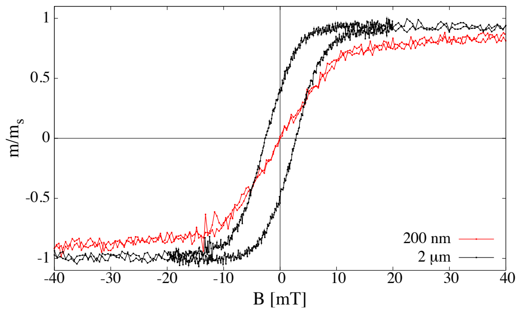


Figure 5: *Top: Magnetic Au/NiFe/Au discs of 200 nm diameter, prepared by laser interference lithography. Bottom: As compared to discs with 2 µm diameter, the hysteresis has entirely disappeared (discs on wafer).*

IV. Conclusions

Microfabricated magnetic discs show a remarkably different magnetic response when they are in suspension, compared to when they are still on the production wafer. At very low frequencies, the magnetic hysteresis loop features a distinct step at 5 mT. This step is not visible in low frequency susceptibility measurements, where at frequencies above 10 kHz a step develops at 1 mT. After several hours in suspension, rotation experiments hint at formation of bigger structures. This behavior in liquids is interesting from a physical point of view, and will have implications for application of these discs in magnetic particle detection and imaging.

References

[1] Löthman, P. A., Janson, T. G., Klein, Y. P., Blaudszun, A-R., Ledwig, M., & Abelmann, L. (2017). Microfabrication and Magnetic Particle Spectrometry of Magnetic Discs. International Journal on Magnetic Particle Imaging (IJMPI), 3(2), [1707001]

[2] Van de Loosdrecht, M. M., Waanders, S., Wildeboer, R. R., Krooshoop, H. J. G., & ten Haken, B. (2017). Differential magnetometry to detect sentinel lymph nodes in laparoscopic procedures. IWMPI 2017, Prague.