Synthesizing Magnetic Particles for Sensor Applications: Sputtering for Printable Inks and Pastes

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Abstract

Printed magnetoresistive sensors are being developed for new applications such as contactless switches and touchless interfaces. However, their limited sensitivity in low magnetic fields has prevented their use in smart textiles and safety wearables. To address this, a scalable approach called MAG4INK has been introduced.
It combines superior morphology control by thin film deposition with advanced printing technologies to create flexible anisotropic magnetoresistive (AMR) sensors with improved sensitivity in low magnetic fields. This is achieved by deposition of thin magnetic films on a sacrificial layer, processing them into powder, formulating printable inks, and using a high-power diode laser array or flash lamp annealing as post-processing. The goal is to achieve a magnetoresistive effect of about 0.5% in magnetic fields of ±6 mT, with the aim of further improving sensitivity in the sub-mT range.

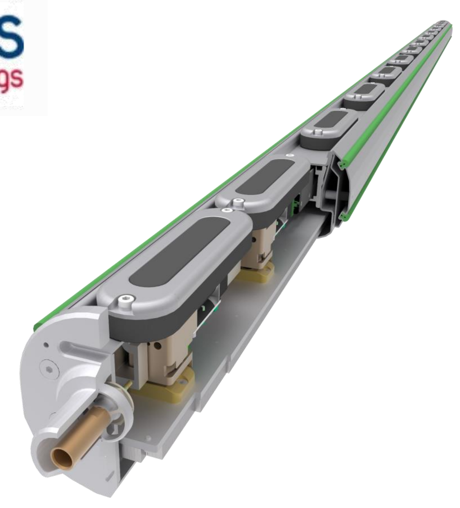
Sputtering of magnetic materials

A strong magnetic field is necessary to compensate the weakening of the magnetic target material

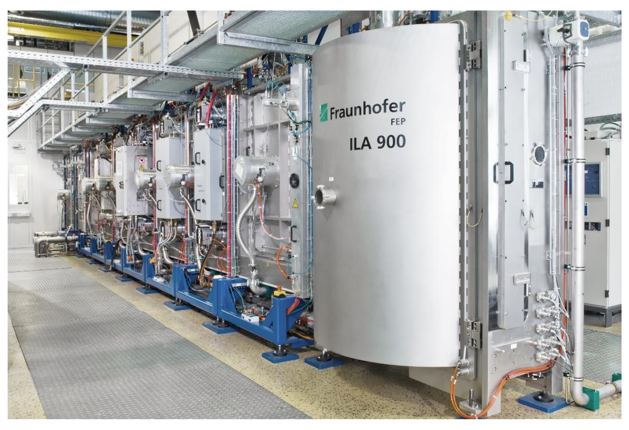
→ sputtering with in-situ adjustable magnet bar enables …

- control of dc-plasmas and discharge voltage
- adjustment of particle energy
- sputtering of target thicknesses up to 2.5 mm for iron targets

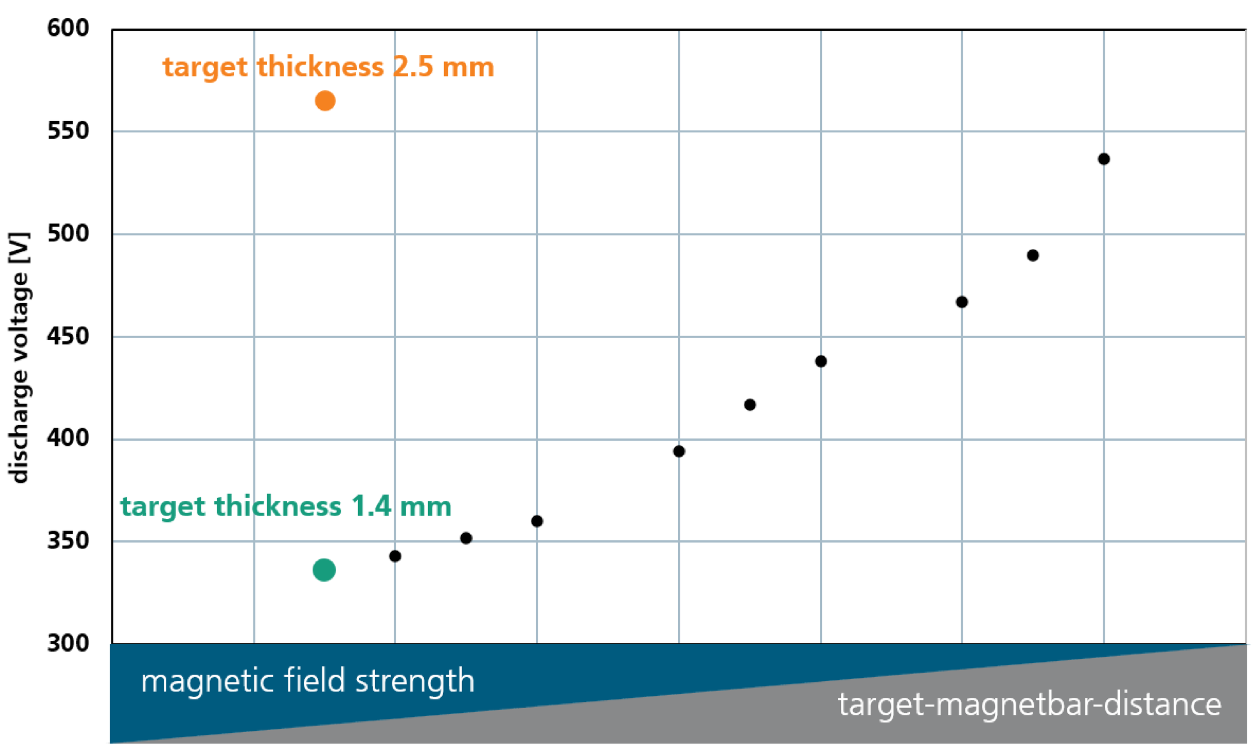
SOLERAS advanced coatings



In-situ adjustable magnet bar

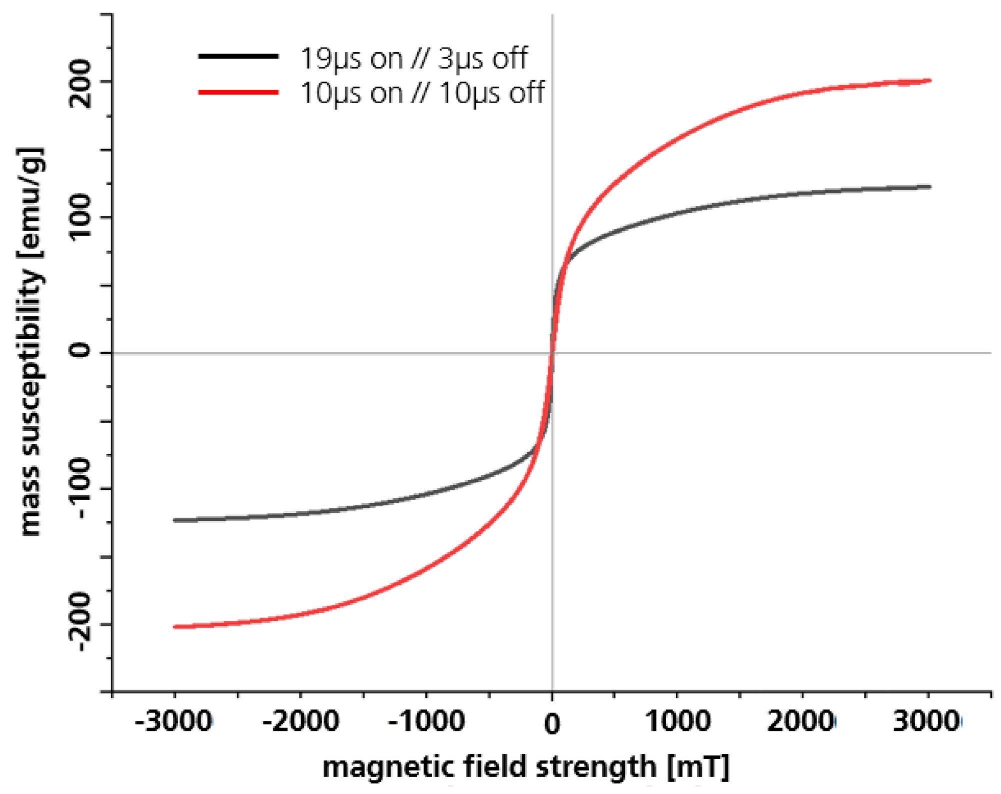


Process/Layer properties	Value
Deposition rate	22…28 $\frac{nm \cdot m}{min}$
$R_{spec.}$	20…24 µΩcm
Power density	4,0 $\frac{kW}{m}$
Target length	0,8 m



Adjustment of the magnetic Fe particle properties by the duty cycle of the plasma

- magnetic characterization of sputtered and lifted off particles by vibrating sample magnetometer (VSM)
- magnetization is controlled by shifting the ratio of pulsed dc-plasmas on/off-time
- lower duty cycle increases the magnetization of the particles

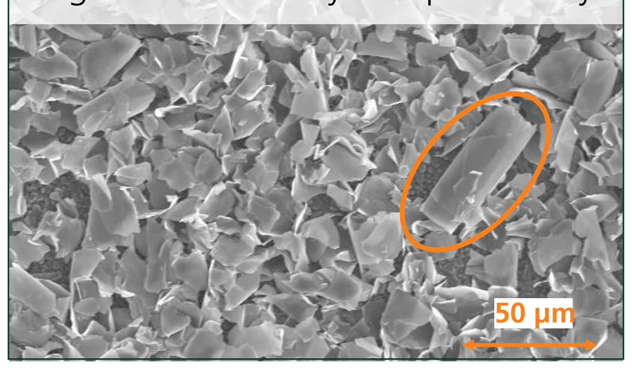


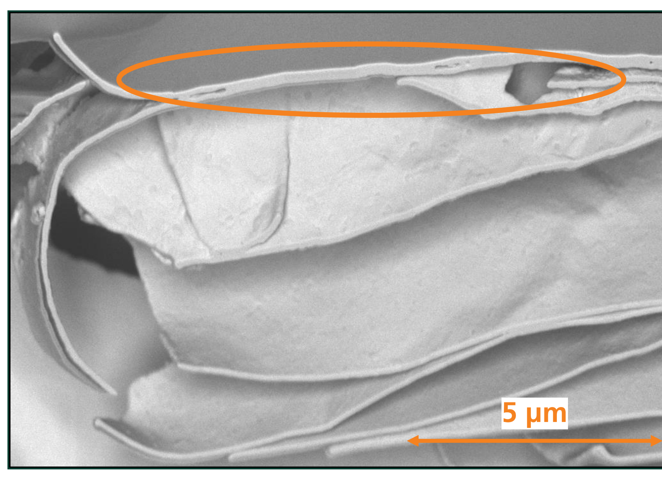
Reducing particles mechanical film stress for higher printability

Sputtering Pressure [Pa]	Mechanical film stress [MPa]
0.6	+ 965
0.15	+ 597

- deposition at lower process pressure reduces the tensile thin film stress of the AMR layer
- besides the higher electrical conductivity, flat flakes with lower mechanical film stress favor the thermal post-treatability

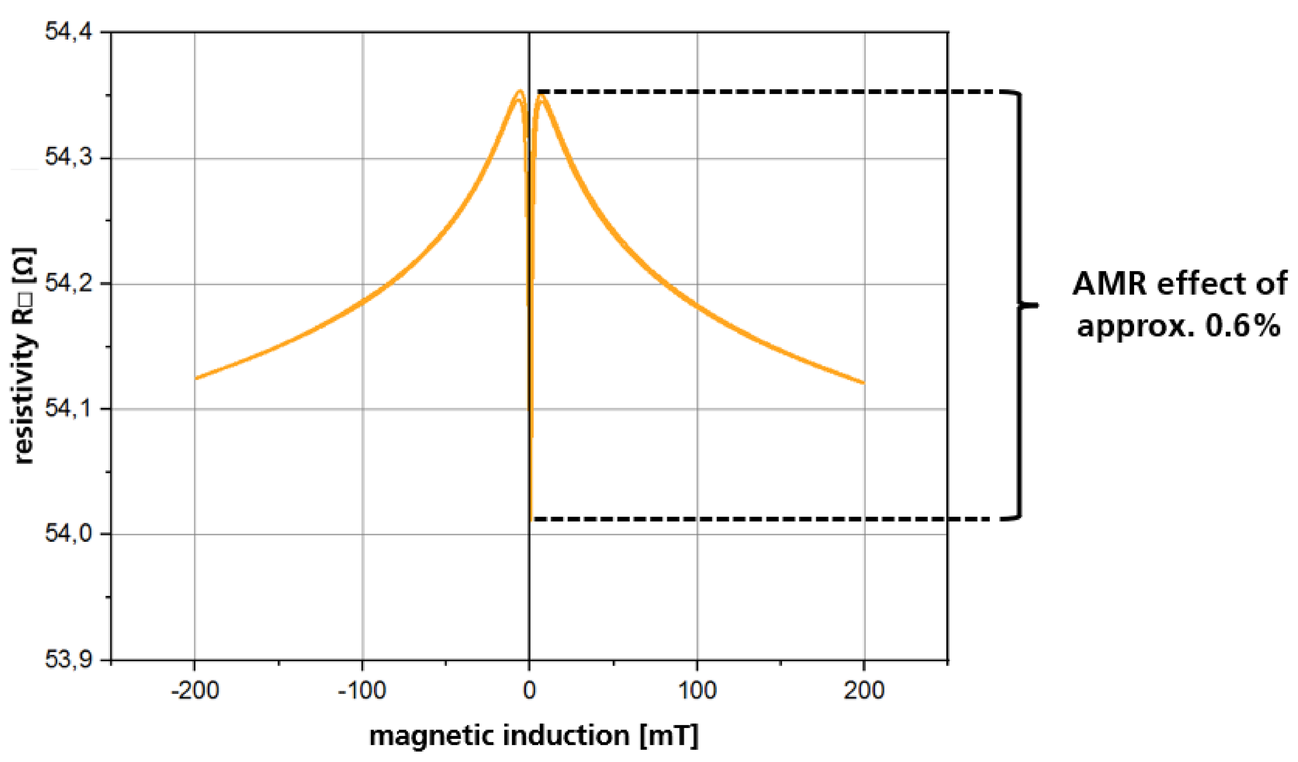
avoid folded, **rolled up particles** for higher conductivity and printability



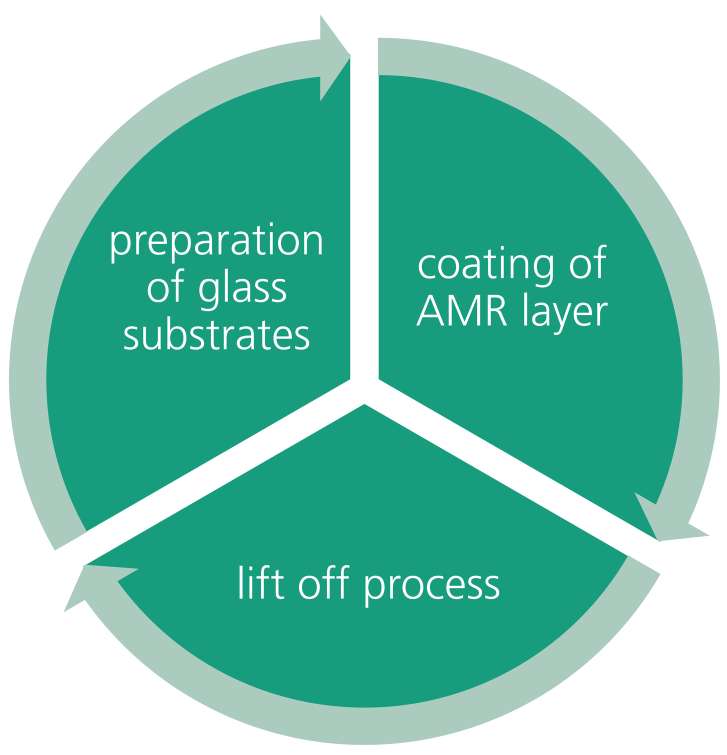


flat sintered NiFe flakes as a result of using high power diode laser as post printing thermal treatment

AMR properties of printed NiFe particles



Productivity of powder manufacturing



- Low-cost and reusable glass substrates
- AMR layers deposited on organic sacrificial layer, solvable in ethanol
- productivity under laboratory conditions: approx. 500 g in 22 weeks (single substrate size 400 x 400mm², coated area approx. 300m²)

→ Sufficient for 80 million sensors (2-3% of current annual production for smart wearables)

Summary and Conclusion

The MAG4INK approach shows that thin film deposition by PVD is a promising approach for the large-volume production of flakes as a raw material for printed flexible sensors. The sputtered magnetic materials can be specifically adjusted to the application by adapting the sputtering process parameters. In the current state of work, NiFe-based sensors with an AMR effect of 0.6% could be produced with a sheet resistivity R□ of 5.7 Ω. The established process chain already enables the production of AMR powder in the lower kilogram range under laboratory conditions in less than half a year - enough for more than 80 million sensors.

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Acknowledgement
Essential results were obtained in the public project „MAG4INK" with support code 03VP09093, funded by BMBF.

Bundesministerium für Bildung und Forschung