Ink-jet printed ferromagnetic $CoFe_2O_4$ thin films

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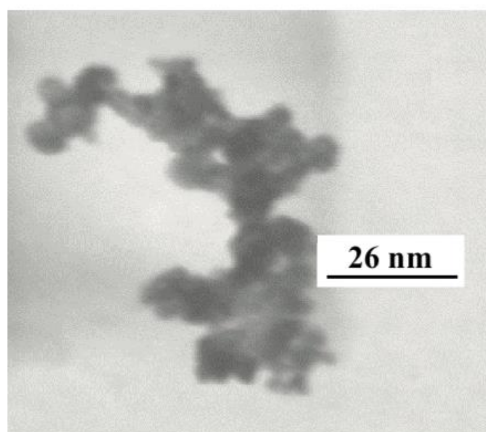
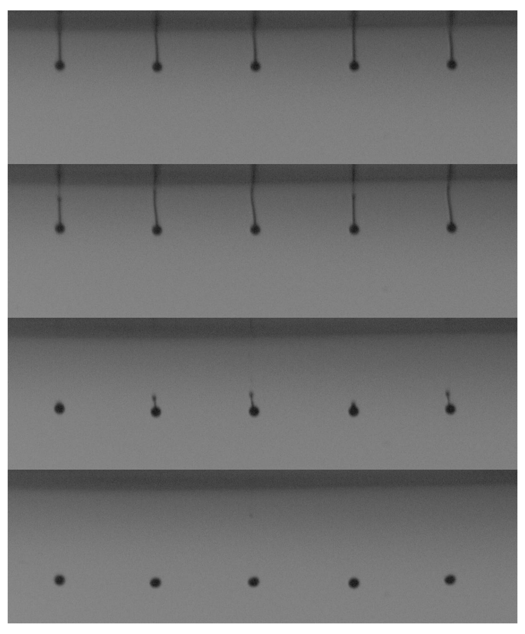
Recent progress with 3-D printing technologies allowed the possibility to obtain accurate micrometer-sized electronic devices consisting of thin films of sintered ceramics or metallic alloys. Direct ceramic ink-jet printing (DCIJP) is a useful multilayer printing system that can produce a wide range of fine ceramics with high resolution. Ferrites, and among them Cobalt Ferrite (**$CoFe_2O_4$**), have attracted the attention of industry and research due to their interesting properties that can be exploited in a wide range of applications, especially in MEMS. Specifically, miniaturized magnetic chips can be manufactured by printing suspensions containing nanosized particles of cobalt ferrite deposited on a target substrate and then sintered to promote densification and adhesion to the substrate.

Ink & Jetting Characterization

> Ink's Characteristics[1][2]

- **$CoFe_2O_4$ nanoparticles** (3 wt.%) in diethylenglycol
- **Average NPs size:** 25 ± 5 nm
- **Density:** 1.20 g/cm^3
- **Surface tension** (25 °C): 40 mN/m
- **Viscosity** (25°C): 30 mPa s

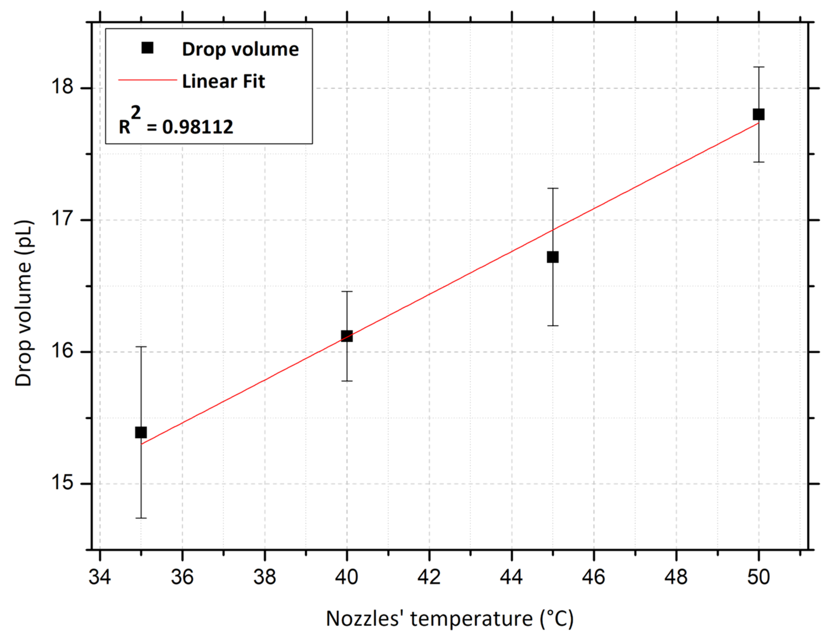




> Optimized Jetting parameters

- **Ejection frequency:** 10-30 Hz
- **Peak pulse potential:** 40 V
- **Nozzles' temperature:** 50 °C
- **Reservoir depression:** 12 mbar

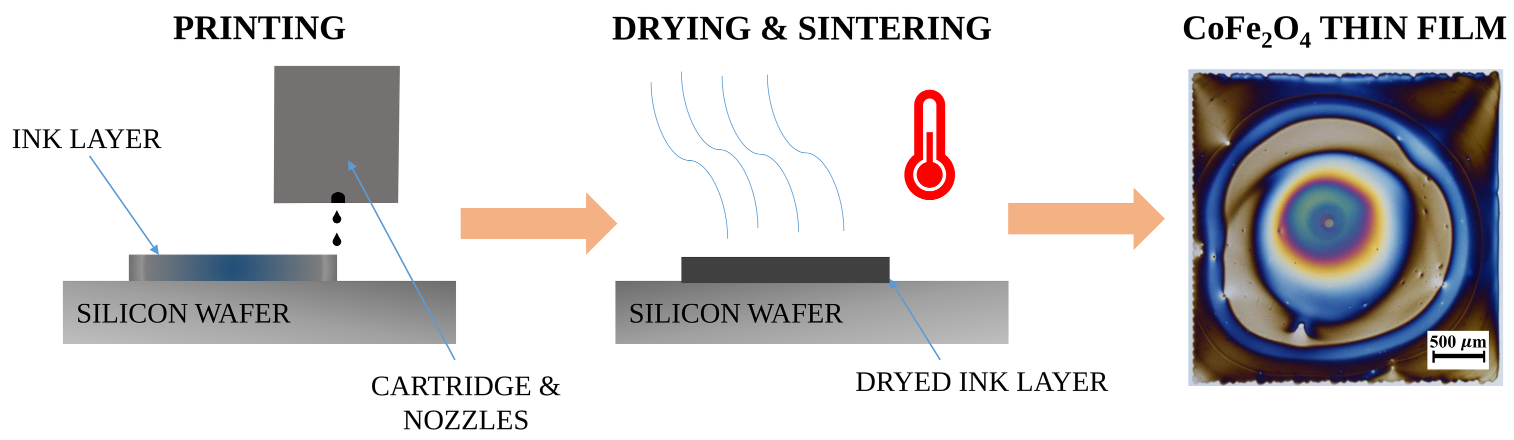
Reliable and stable drop formation above 40 °C. Drop's size, velocity and dimensional accuracy increase with increasing temperature.



Printing & Fabrication process

> Apparatus: CeraDrop® CeraPrinter F-series

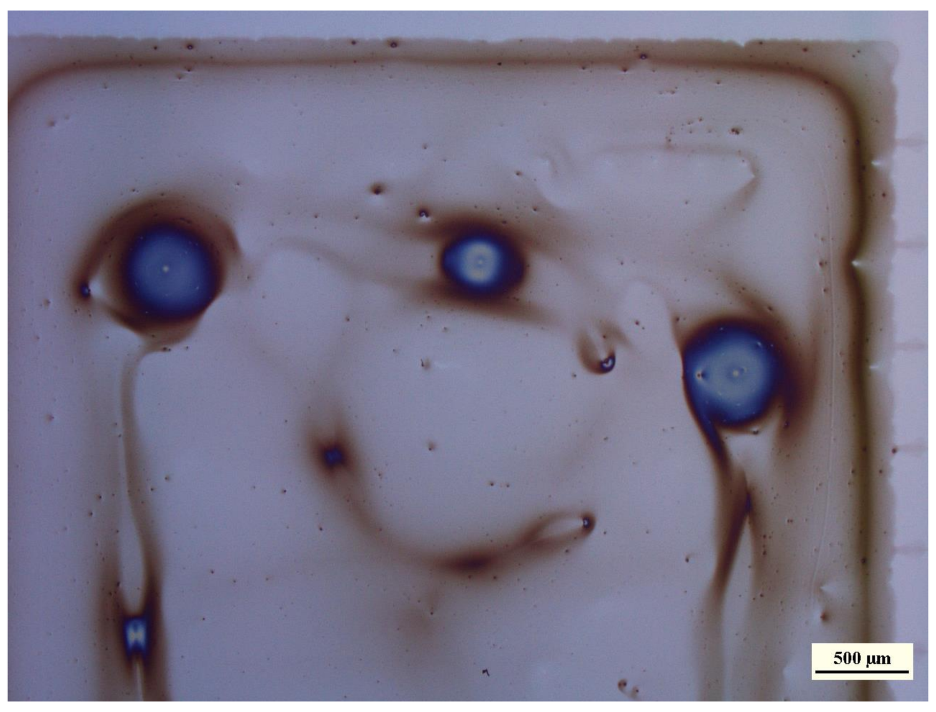
All-in-one State-of-the-art Prototype 3D Printer that combines Inkjet and Aerosol Jet® technologies

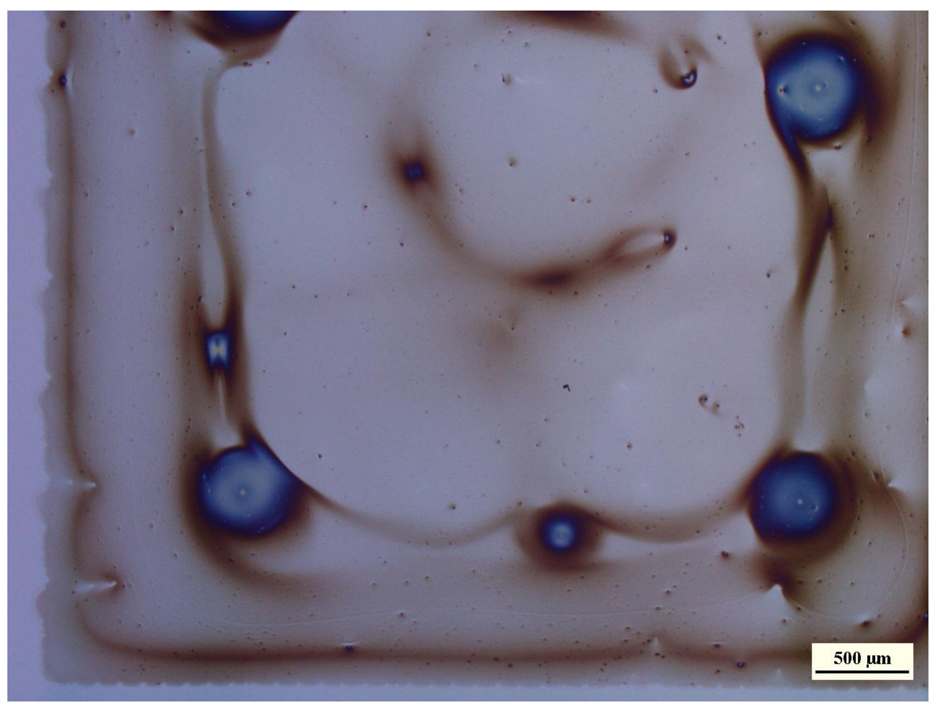


> Sintering ramp

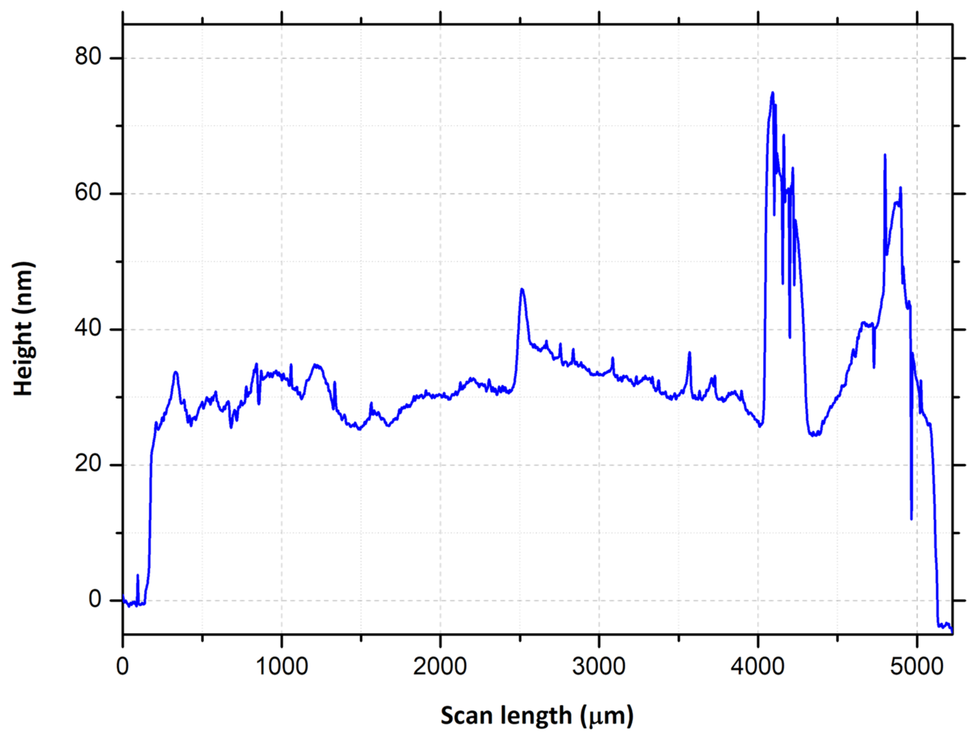
1. 250 °C, dwell time 30 min, heating rate 5 °C/h
2. 800 °C, 30 min, 5 °C/h

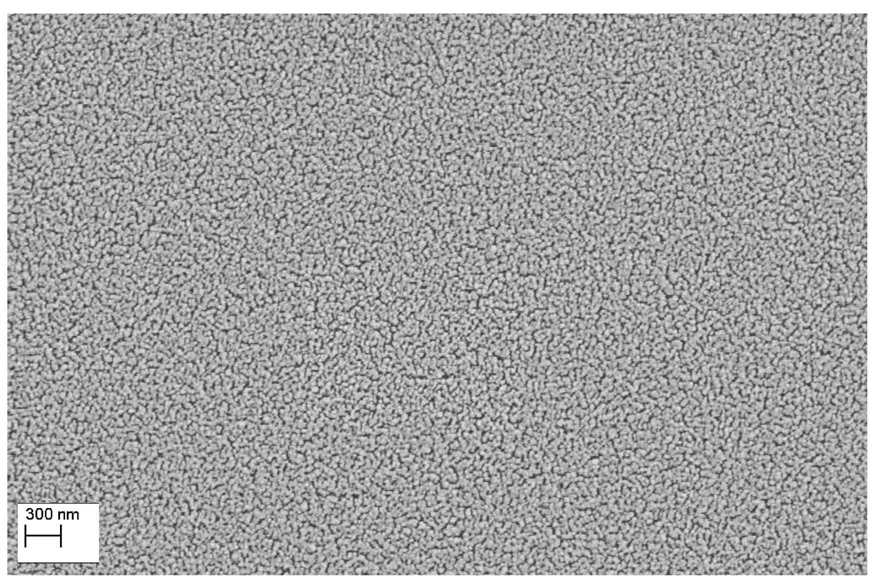
Film characterization

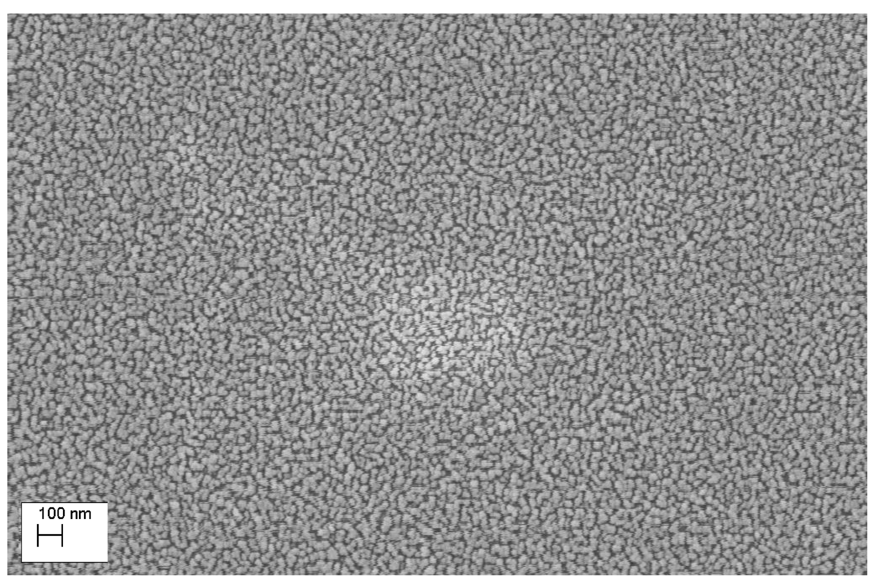




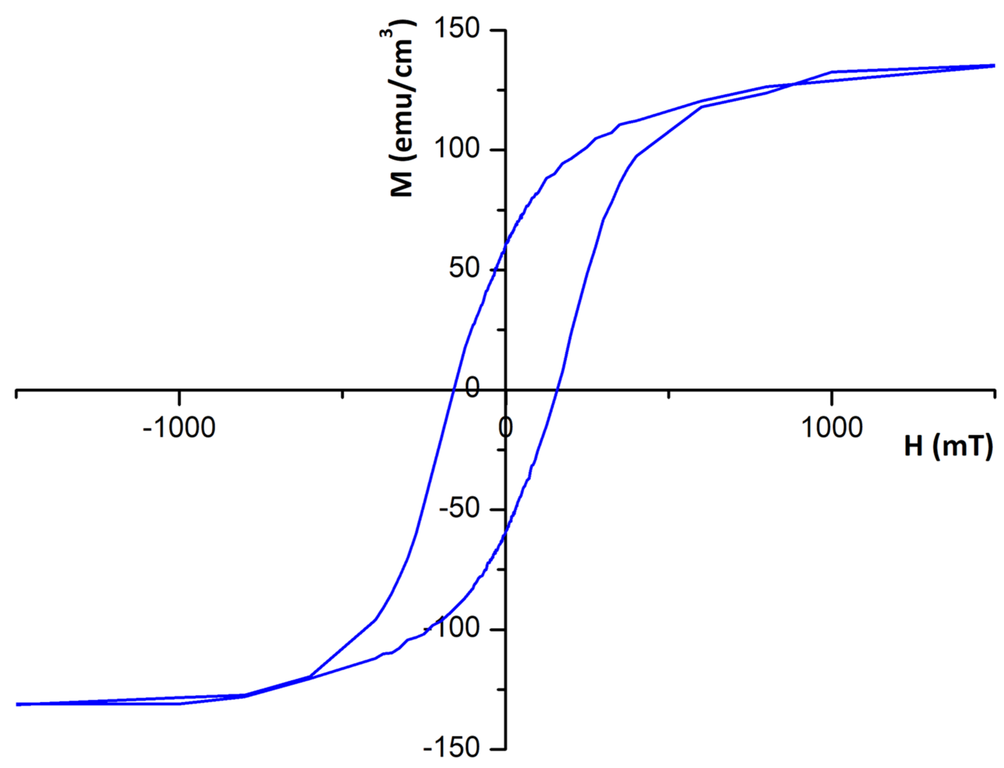
> Squared figures with a side of 5 mm
> Average film thickness: **39 nm**
> Inhomogeneities in the film are caused by shrinking of solvent during drying
> SEM micrographs show homogenously distributed **nanometric grains** throughout the film, with extensive **necking** between them that confirms the sintering behavior during thermal treatment.







Magnetic characterization



> Saturation magnetization (M_S): 130 emu/cm^3
> Remanent magnetization (M_R): 62 emu/cm^3
> Coercive field (H_C): 162 mT

Conclusions

$CoFe_2O_4$ nanometric thin films were successfully ink-jet printed onto a Silicon wafer by using a nanoparticles' suspension. Jetting and printing parameters were carefully studied and fixed in order to ensure a reliable printing process. Films present an average thickness of 39 nm and an homogeneous nanostructure, even though surface inhomogeneities can be found. Magnetic characterizations evidence an "hard" ferromagnetic behavior that can exploited in MEMS.

References

[1] D. Gardini et al., J. Nanosci. Nanotechnol., 2008, vol. 8, no. 4, pp. 1979–1988
[2] D. Gardini et al., J. Nanosci. Nanotechnol., 2015, vol. 15, no. 5, pp. 3552-3561

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