Advanced (magnetic) nanostructures - from lab to fab: challenges and opportunities

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General approach

- A wide variety of nanomaterials and nanostructures - studied extensively in the lab - are trying to reach the status of industrial use in various industries (medical, automotive, energy, security, space, etc.).

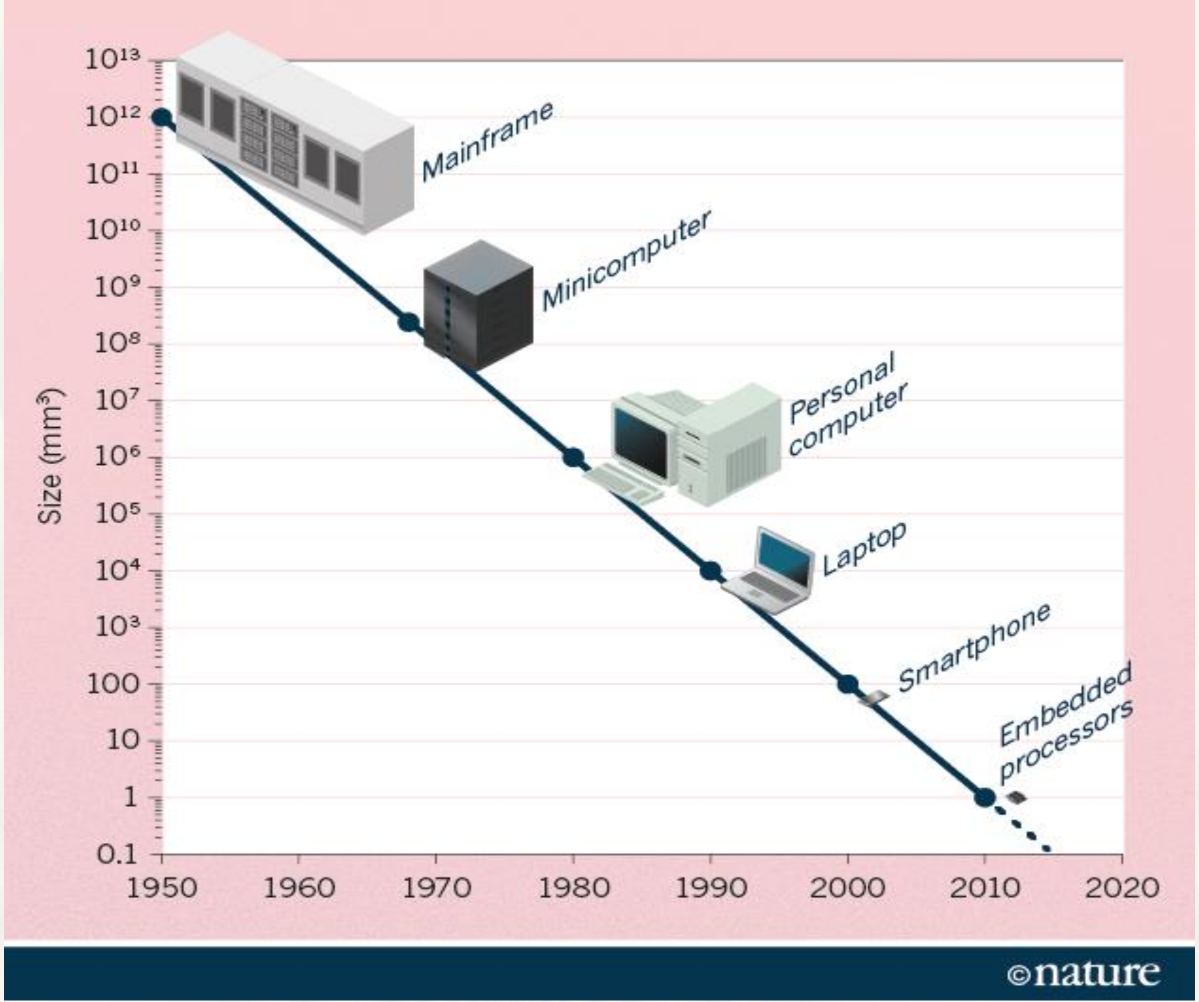
- The same is valid for magnetic nanomaterials, which try to penetrate state-of-the-art applications in IT (magnetic logic, spintronics, novel data storage media), energy (energy harvesting, magnetic refrigeration, nanomagnets), medical research (cancer diagnosis and treatment, MRI, drug delivery, micro- and nanofluidics) or climate monitoring (sensing).

- Limitations and inertia of industrial sector, especially large companies (e.g., adoption of novel materials to replace silicon steel)
    - Require significant investments (workforce, equipment, know-how, IPR)

Bottleneck creates opportunity

Current technological limitations of the microelectronics industry based on semiconductor integrated circuits significantly affect the pace of progress in information technology (IT) applications.

Thus, **the IT industry is in search of a reliable successor for the silicon technology** → **spintronics, magnetic logic, magnonics**



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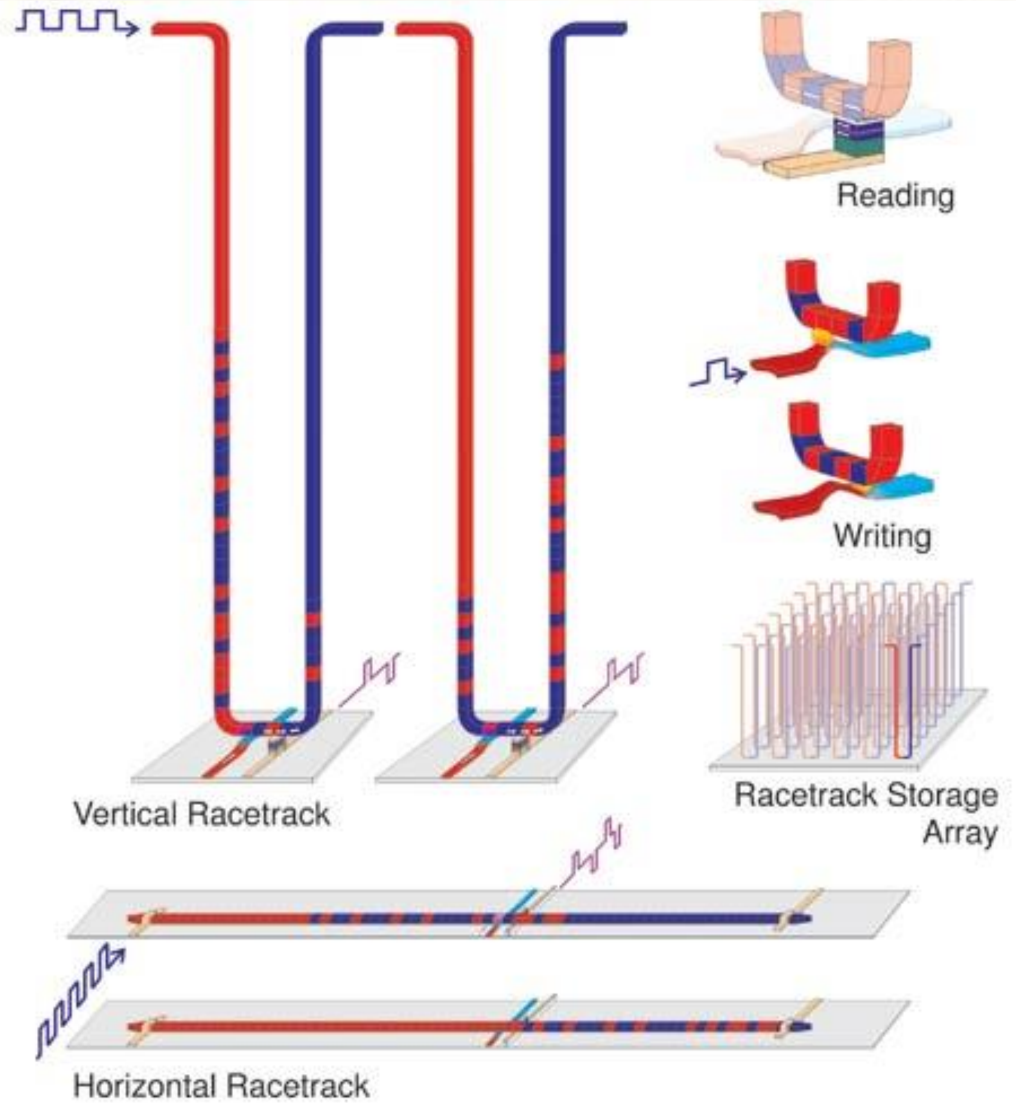
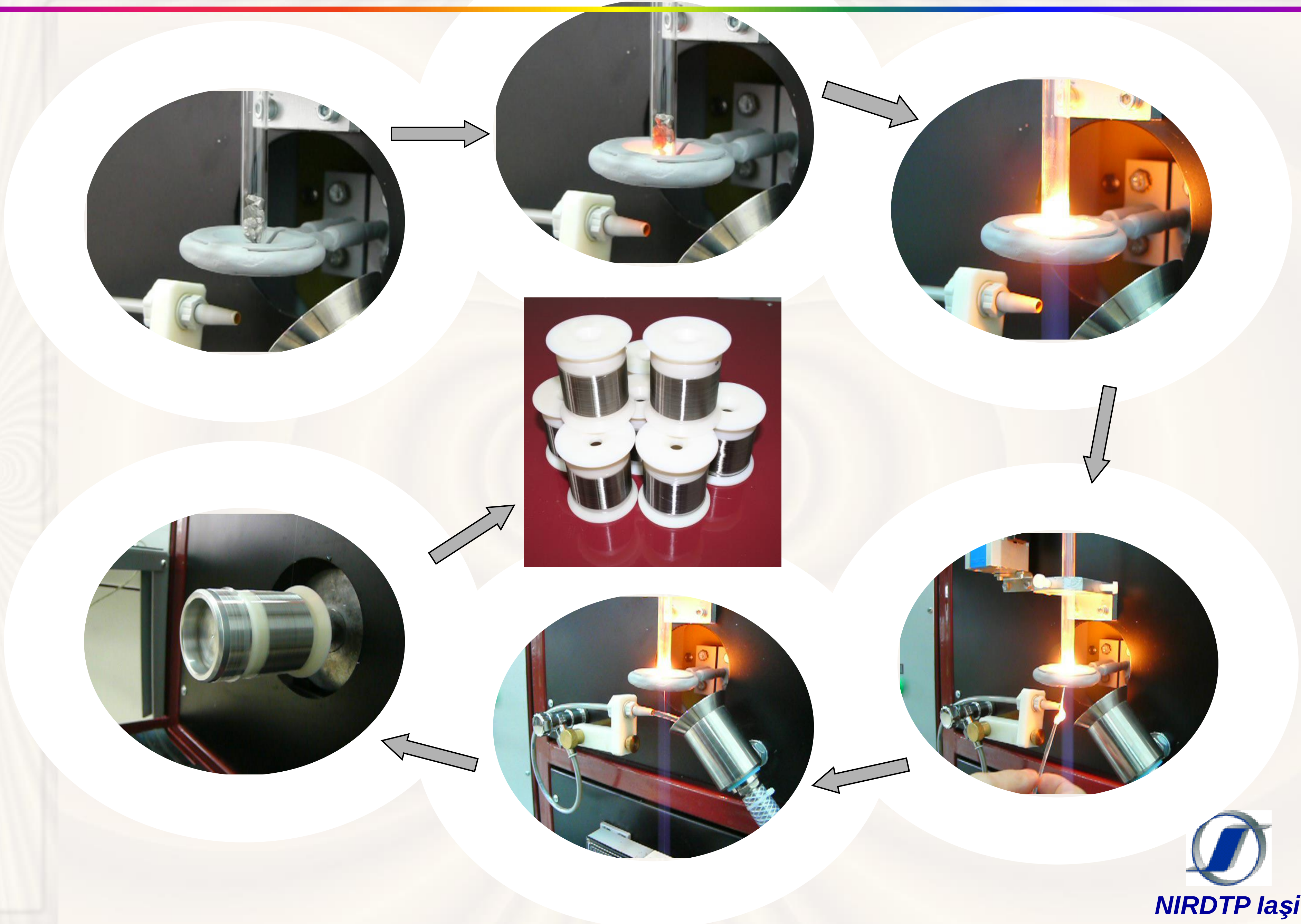
Bottleneck creates opportunity



Vertically oriented nanowires (top left, middle) illustrate how electric current is used to slide tiny magnetic patterns around the nanowire "racetrack" where a device can read and write data. A device reads data from the stored pattern (top right) by measuring the magnetoresistance of the patterns. Writing data (the two images below the read head) can be done by applying an electrical current to a second nanowire at a right angle to the data-storing wire. It is possible to fabricate the nanowires in a vertical array (middle right) and horizontally (bottom two images).

S.P. Parkin *et al.*, Science 320(5873) (2008) 190

Magnetic microwires → nanowires (RQ)



Challenge: characterization @ nanoscale

- **new measuring techniques need to be designed and implemented, adequate for reduced scale sensitivity**

Since the glass-coated nanowires and submicron wires are very tiny materials, the conventional methods for measuring their magnetic properties are not sensitive enough.

Consequently, we used:

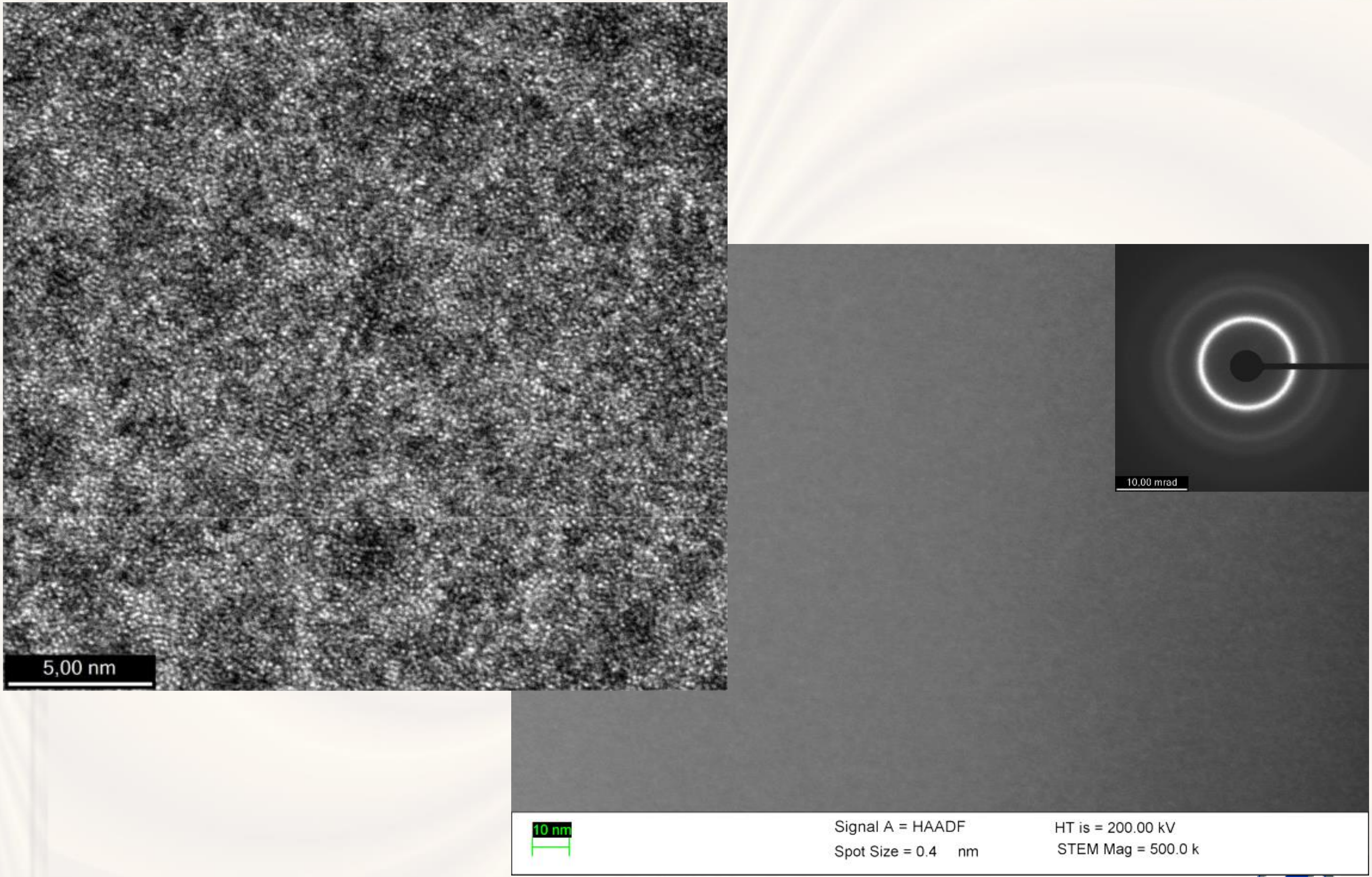
1) a specially designed fluxmetric equipment - for magnetic measurements

Corodeanu *et al.*, IEEE T Magn 47, 3513 (2011)

2) a modified Sixtus-Tonks method specially designed in our lab for very thin samples – to determine the domain wall velocity along the wire length

Corodeanu *et al.*, Rev Sci Instrum 82, 094701 (2011)

Novel structures in magnetic nanowires - peculiarities



AQ

Chiriac *et al.*, Crystals 7(2), 48 (2017)

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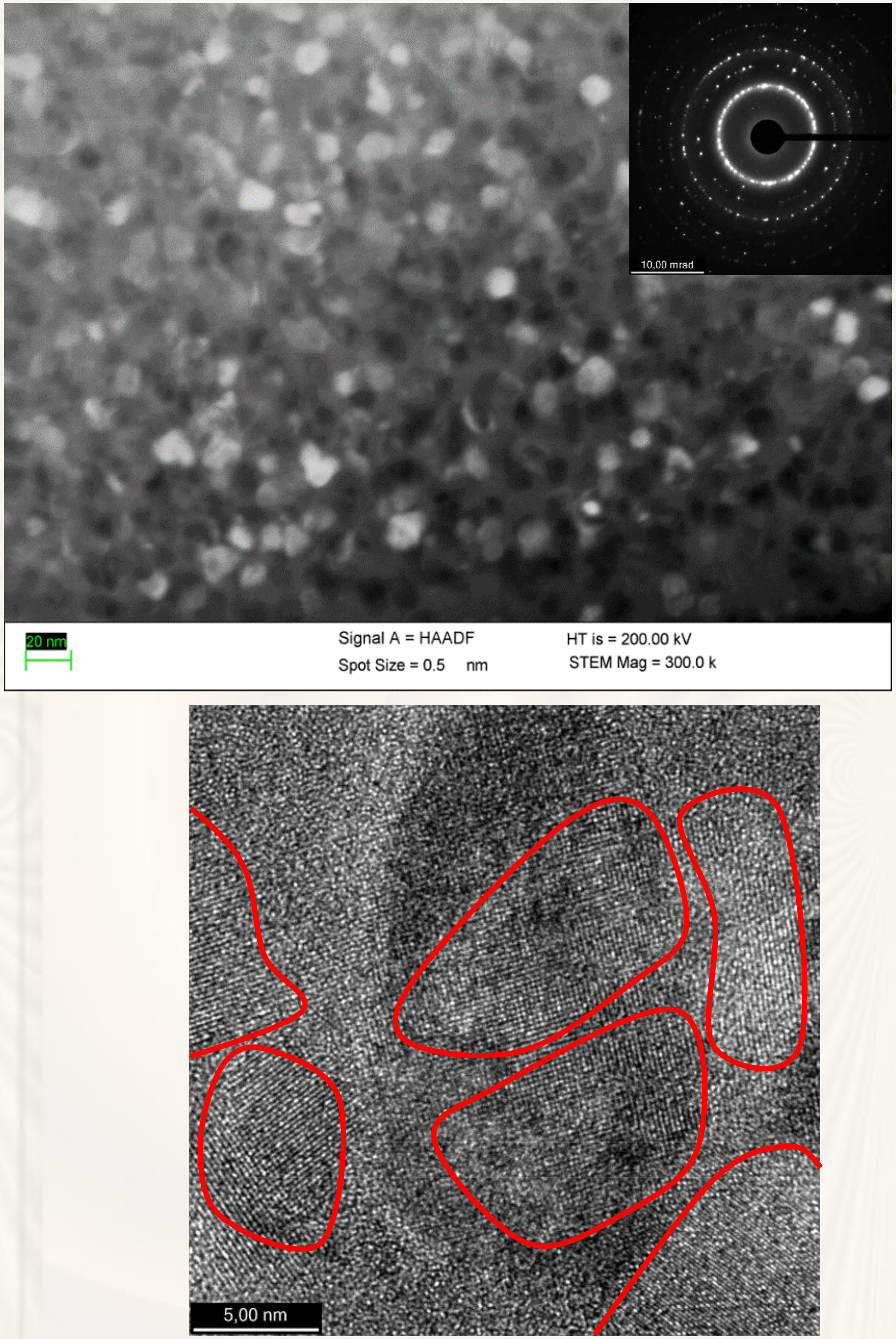
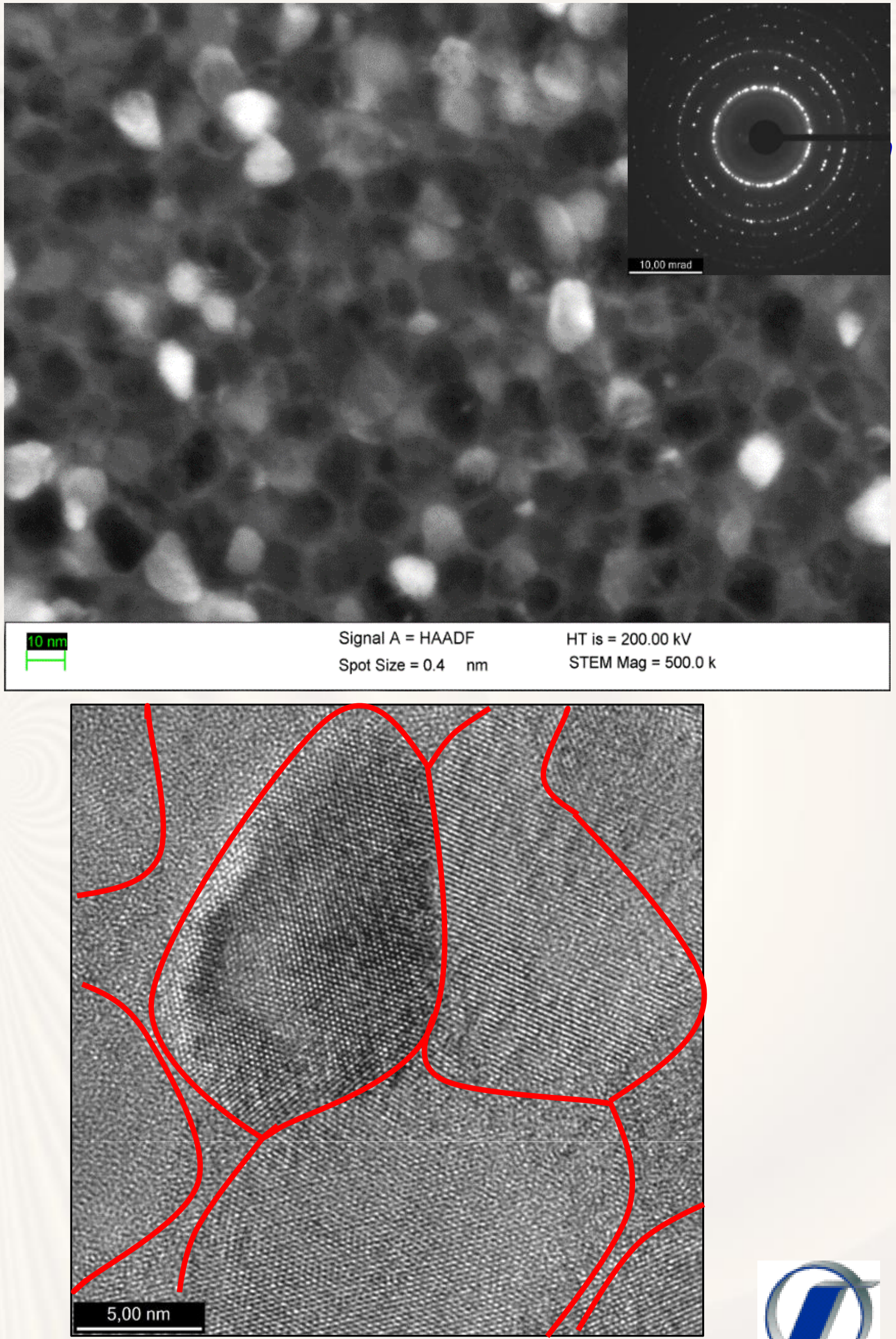


TT @ 550^{0}C, 60 min.



TT @ 600^{0}C, 60 min.

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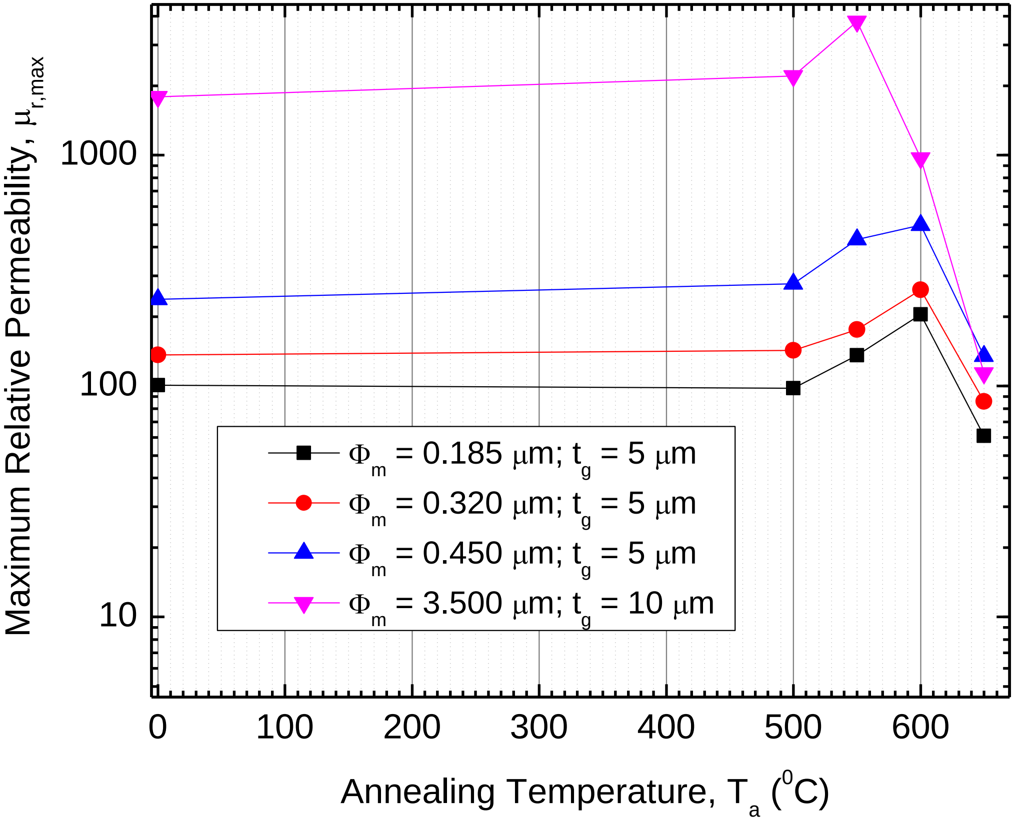
Novel structures in magnetic nanowires - peculiarities

$\mu_{r,max}$ of the reference microwire displays a peak at 550^0C, whilst the values for ultrathin wires do not reach such maxima before 600^0C.

Thus, the magnetically softest nanocrystalline phase is formed at larger T_a for thinner wires, since larger temperatures are needed to relieve the stresses induced by the thick glass coating in the ultrathin metallic nucleus.



Chiriac *et al.*, Crystals 7(2), 48 (2017)

Magnetic nanowires (RQ) – from lab to fab

- potential candidates in domain wall conduits for future magnetic domain wall logic based devices (they could replace nanowires prepared through more complicated and expensive techniques, such as electron and ion beam nanolithography);

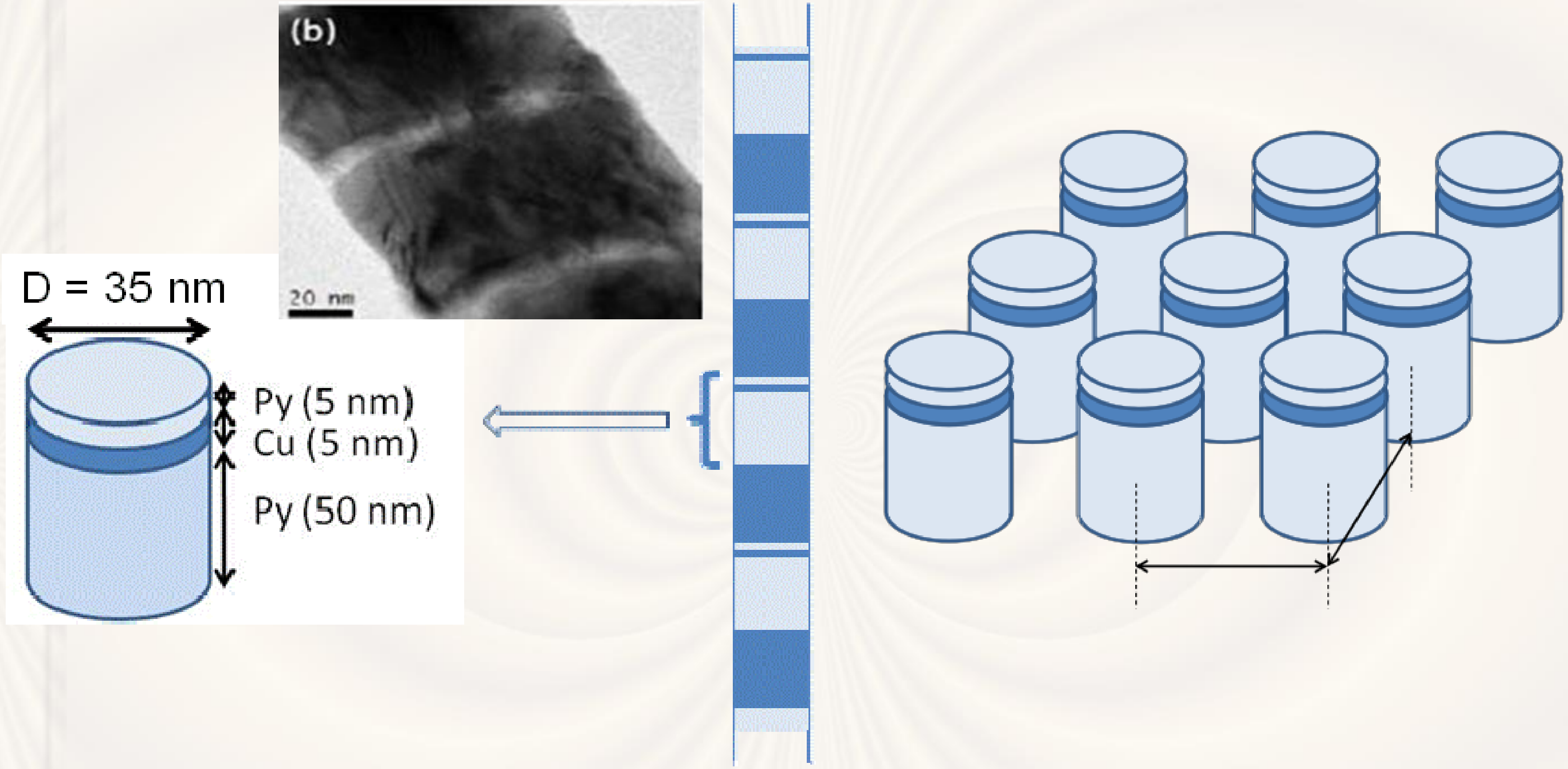
- miniature sensing elements in micro- and nanosensors aimed for implantable or non-implantable medical devices, e.g., stress or deformation microsensors;

- magnetic micro-sensors such as magnetic field, position, identification, security, non destructive testing with applications in the electronic, automotive, aeronautics, space industry, etc.

- high frequency applications - due to their extremely small transverse dimensions, where they could be employed to create radio wave absorbing structures for electromagnetic shielding applications

Magnetic nanowires (ED) – from lab to fab

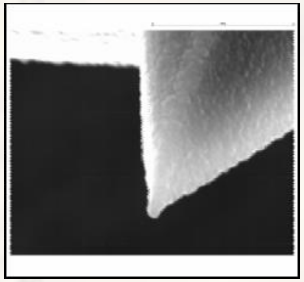
From a single spin valve oscillator to large arrays of spin torque nano-oscillators (STNOs)



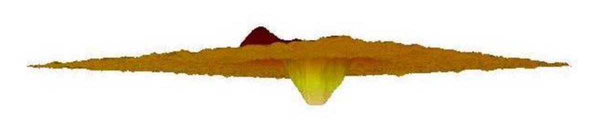
<u>Electrodeposition:</u> versatile and low cost approach for large arrays of STNOs

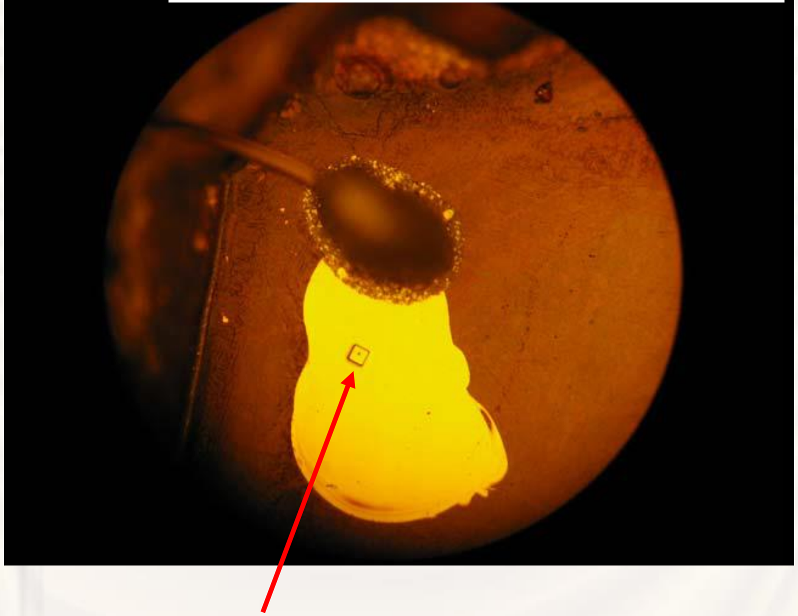
Magnetic nanowires (ED) – Device fabrication

I. AFM conductive tip for indentation



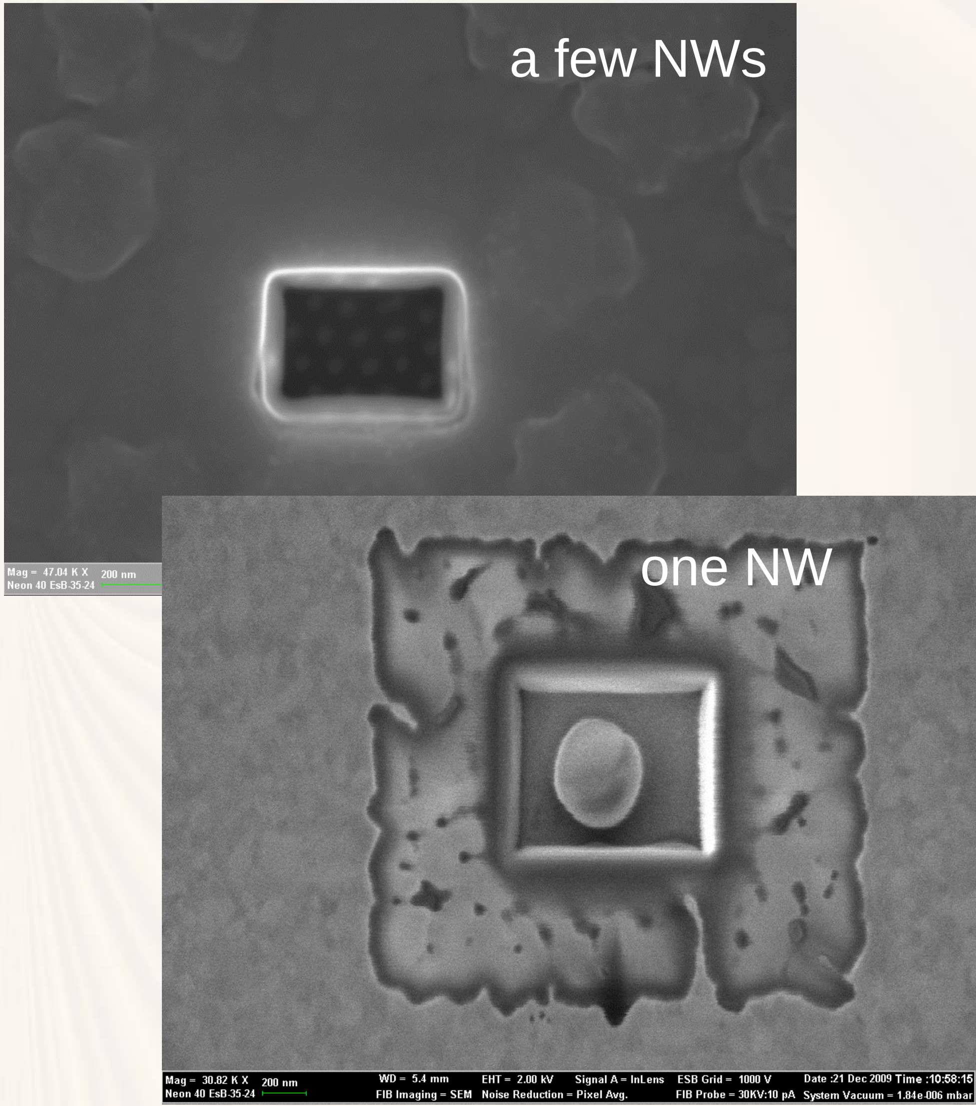
Shape of the nano-indent





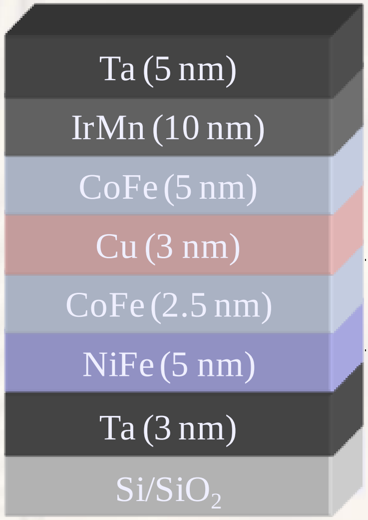
30X30 µm^2 area where the AFM nanoindentation is done

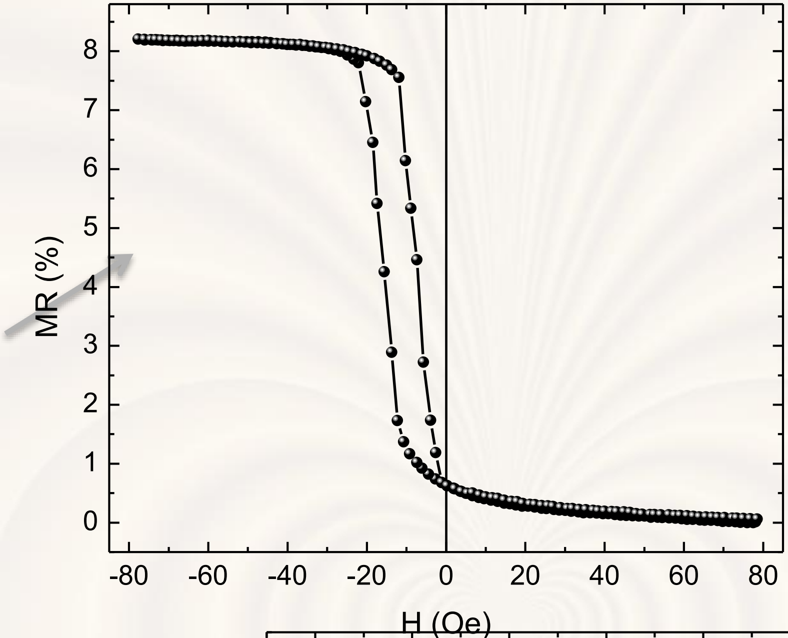
II. New procedure for making contacts on a single nanowire by using FIB



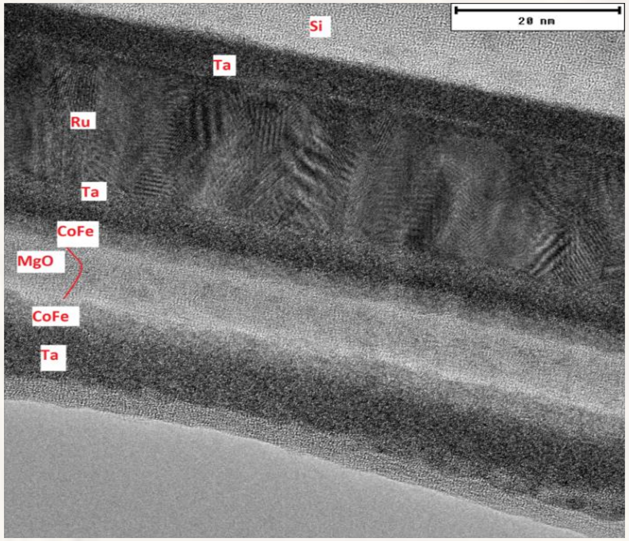
Magnetoresistive thin films for sensing applications

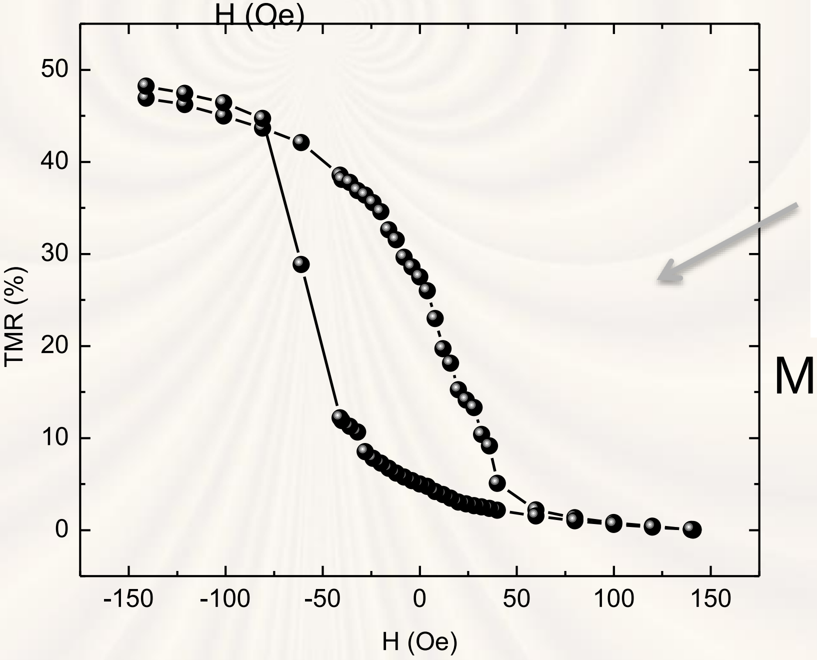
GMR thin films



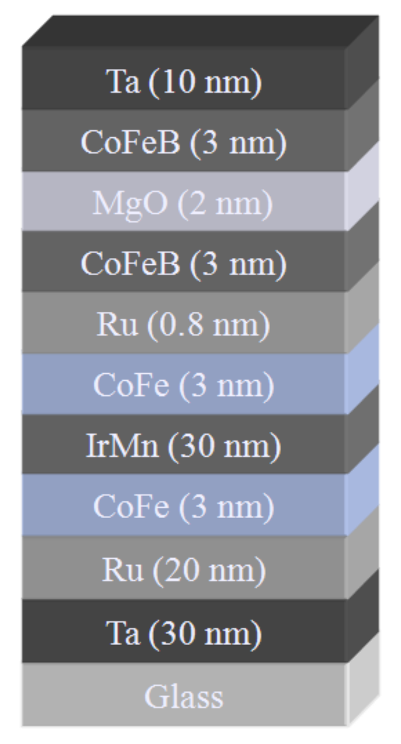


Spin valve multilayer stack





TMR thin films



MTJ multilayer stack

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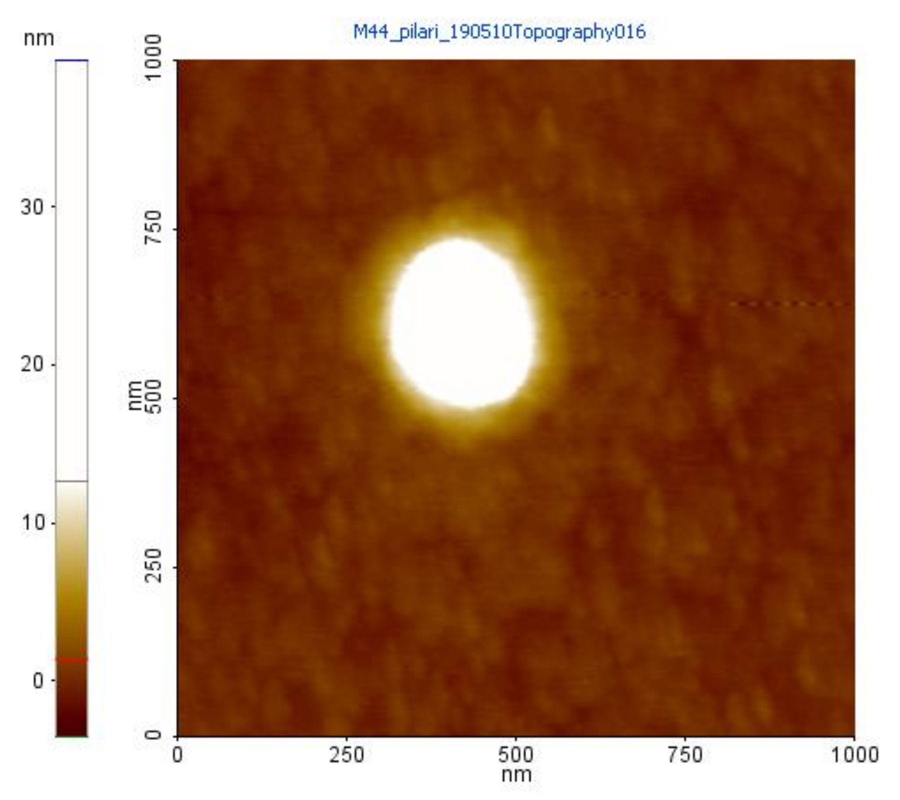
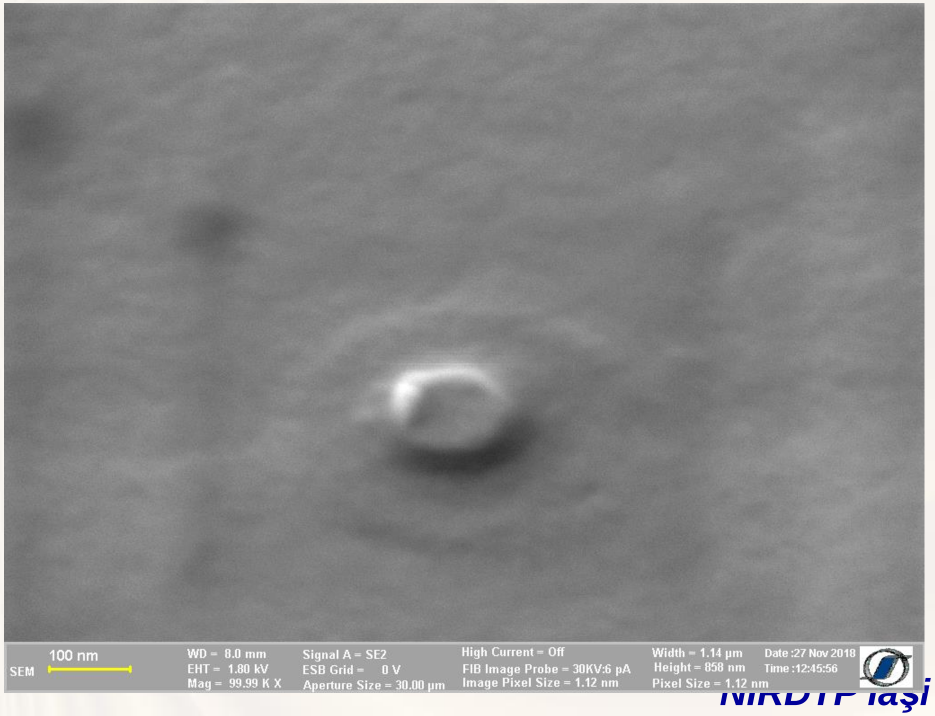
Magnetic nanopillars (RF sputtering + lithography)

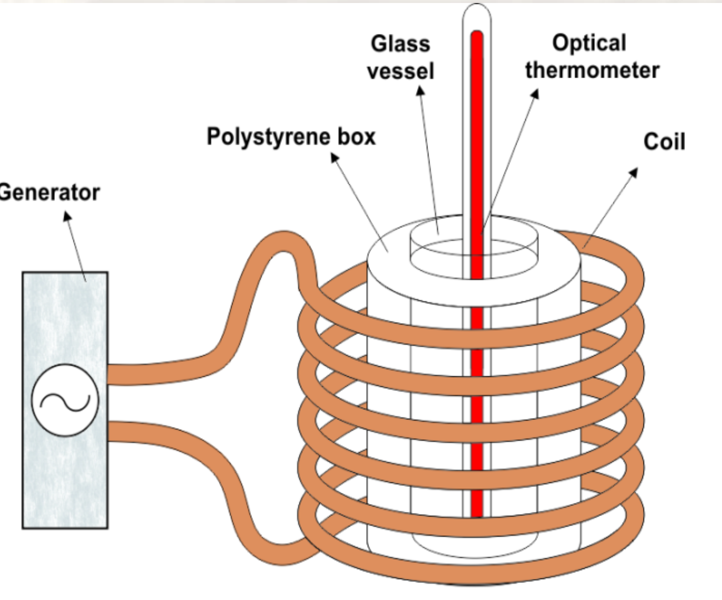


The GMR effect of the magnetic layers of a spin valve can convert the magnetic precession into microwave voltage signals and turn the valve into a Spin Torque Nano-Oscillator (STNO).

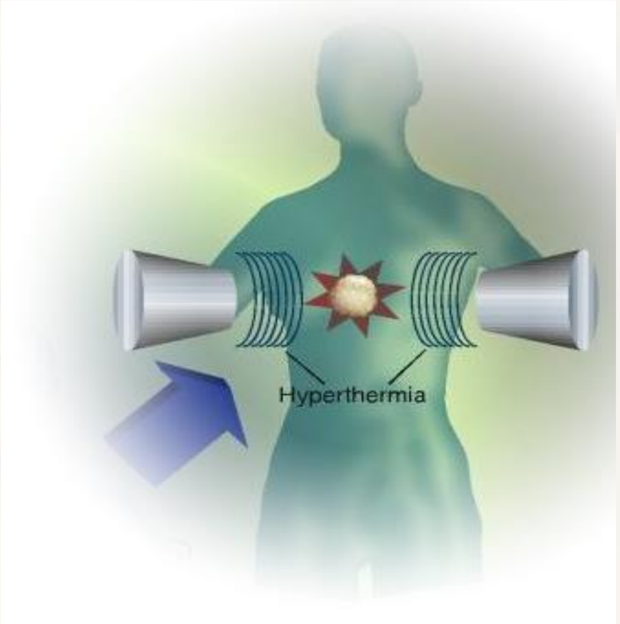


WD = 8.0 mm
EHT = 1.80 kV
Mag = 99.99 K X
Signal A = SE2
ESB Grid = 0 V
Aperture Size = 30.00 µm
High Current = Off
FIB Image Probe = 30KV:6 pA
Image Pixel Size = 1.12 nm
Width = 1.14 µm
Height = 858 nm
Pixel Size = 1.12 nm
Date :27 Nov 2018
Time :12:45:56

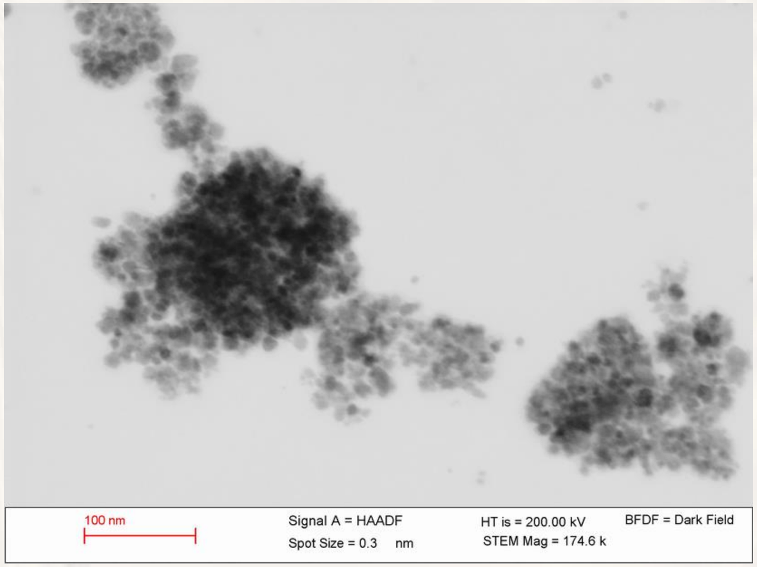
Magnetic hyperthermia using low T_C magnetic NPs



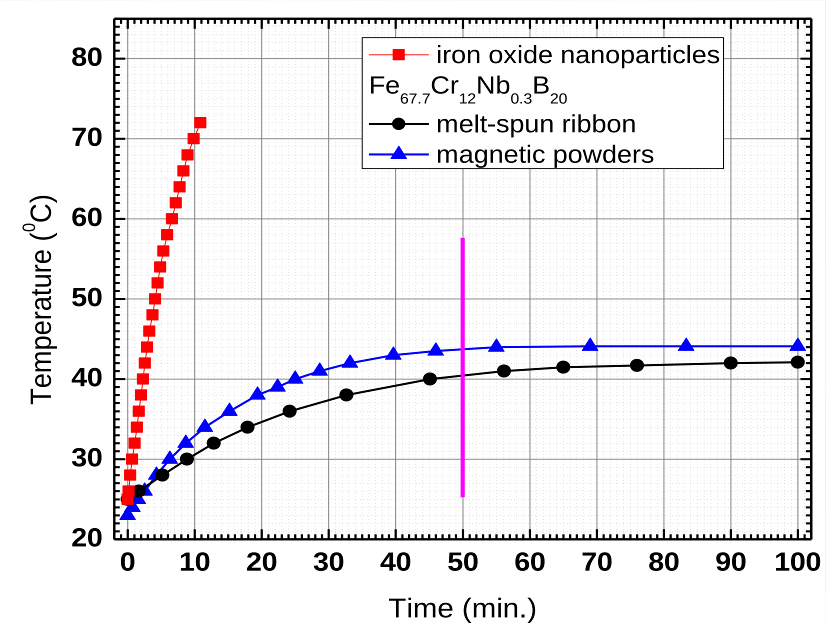
Chiriac *et al.*, Sci Rep 8 (2018) 11538
WO 2015/171008 A2
US 10,290,406 B2



FeCrNbB nanopowders



Time dependence of temperature on heating time



Microfluidic device for nanoparticles detection

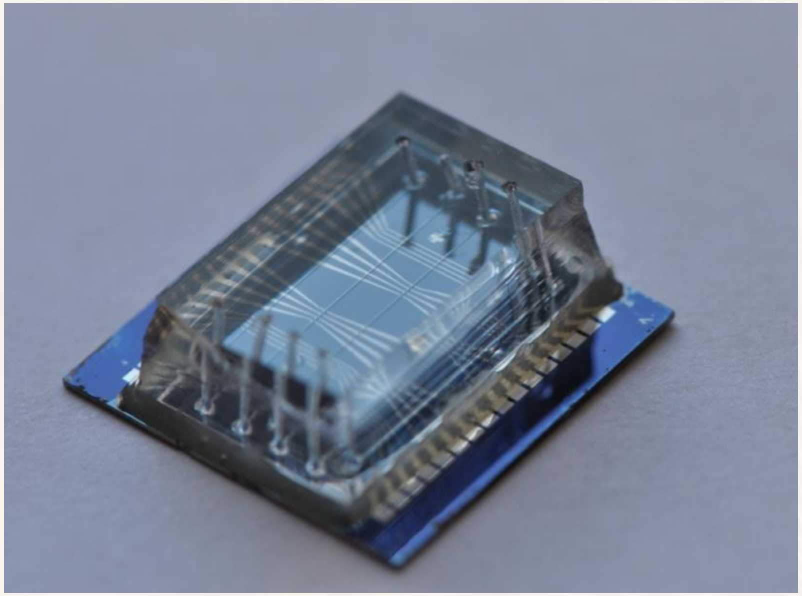
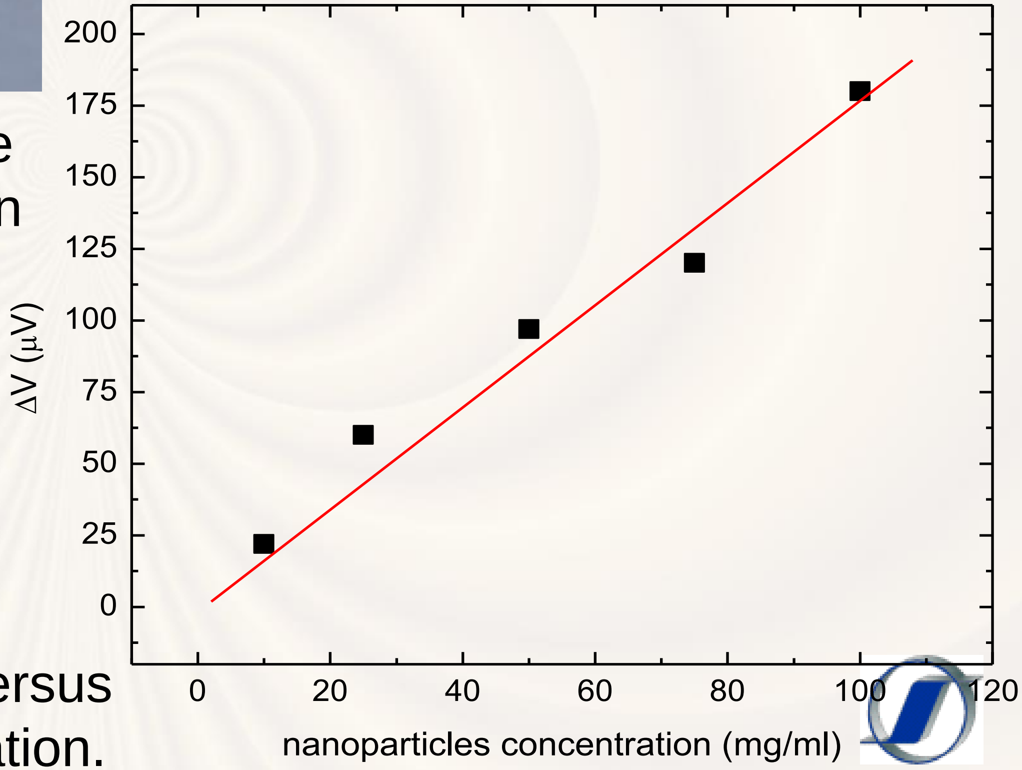


Photo of the microfluidic device used for nanoparticles detection

16 spin valve sensors (100 μm x 2.5 μm)

4 microchannels (100 μm x 100 μm)

4 sensors in each channel



Sensor output voltage versus nanoparticles' concentration.

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