Arrays of Magnetic Nano Particles Using Self-Organised Semiconductor Surfaces

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Independent Dots

Requirement / Goal

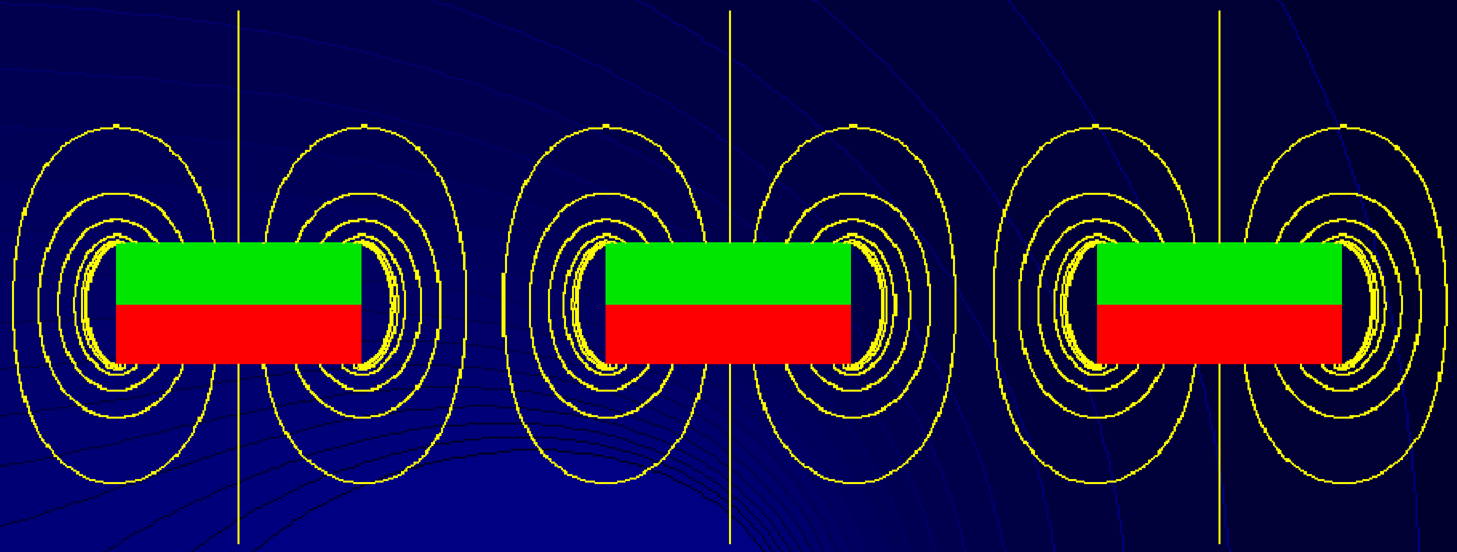
- Decrease of size / increase of density
- Stray field (e.g. for memory readout)

Handicap

- Super paramagnetic limit ($E_{anisotropy} < 25\ k_B T$)
- Unavoidable stray field coupling / no independent particles

Possible solution

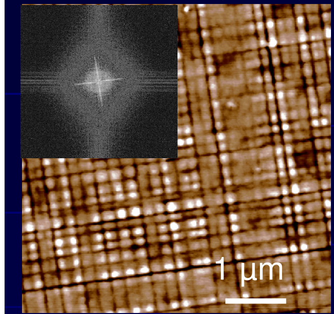
- Large anisotropy to overcome coupling



SiGe and GaSb

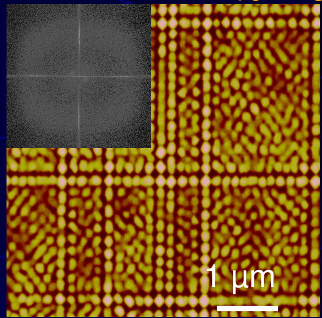
SiGe

Cross-hatch pattern $Si_{75}Ge_{25}$



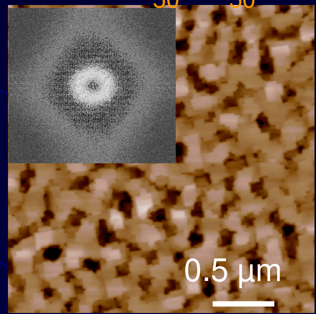
z-scale: 5 nm

{105} faceted cross-hatch $Si_{70}Ge_{30}$



z-scale: 15 nm

{113} faceted mesa-structures $Si/Si_{50}Ge_{50}$

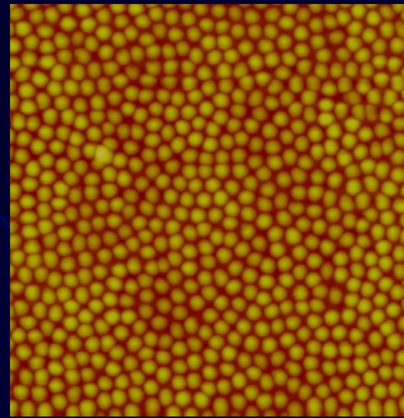


z-scale: 20 nm

- Strain relaxation during epitaxial growth and metal evaporation
- Dislocation network
- 4-fold symmetry
- 200 nm periodicity
- Shadow deposition
- Tilted surfaces
- No capping
- Favourable for in-plane magnetisation

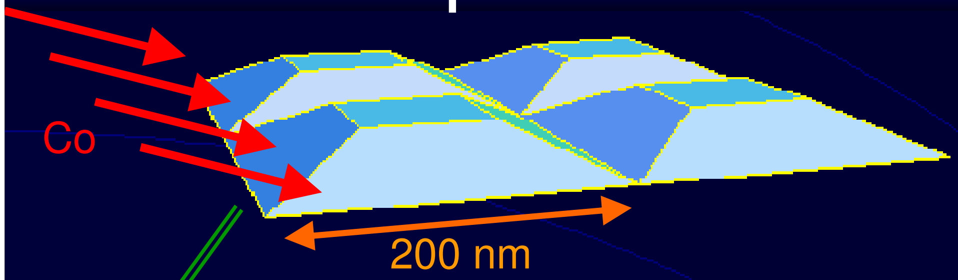
GaSb

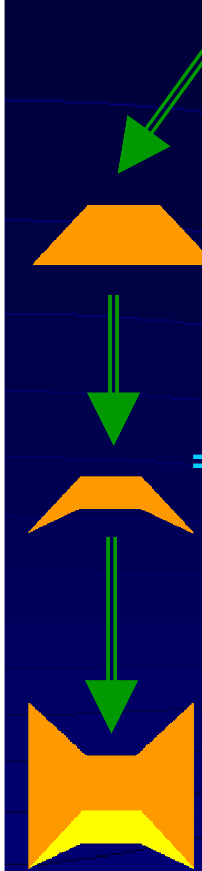
AFM



- Inhomogeneous ion sputtering of metal / semiconductor heterostructures
- Curvature dependent sputter yield
- 6-fold symmetry
- 50 nm periodicity
- Cut a continuous film
- Flat discs
- GaSb capping
- Favourable for out-of-plane magnetisation

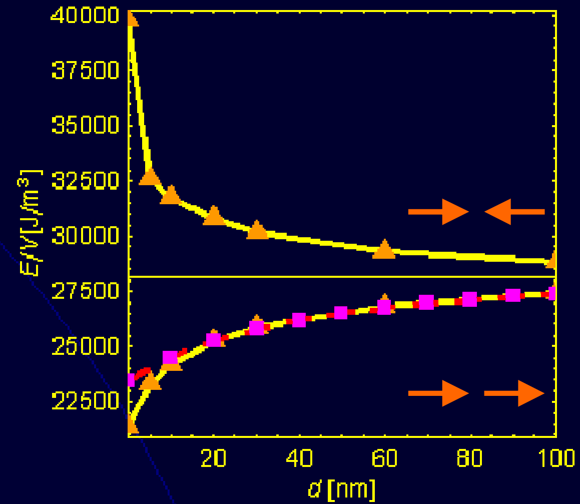
Shadow deposition on SiGe "mayan" pyramids

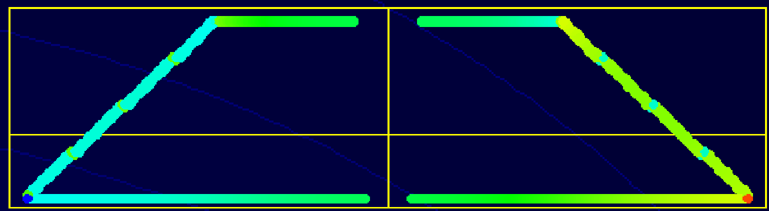




Interaction energy of 10 trapeziums

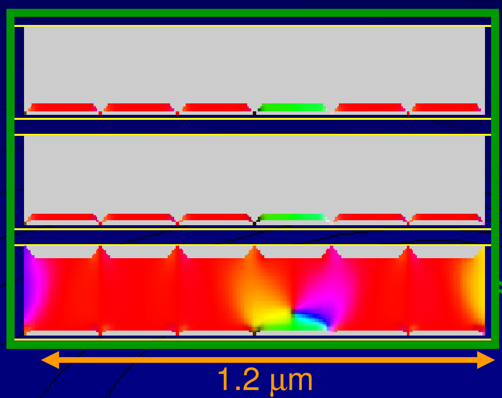
(7th order multipole interaction)

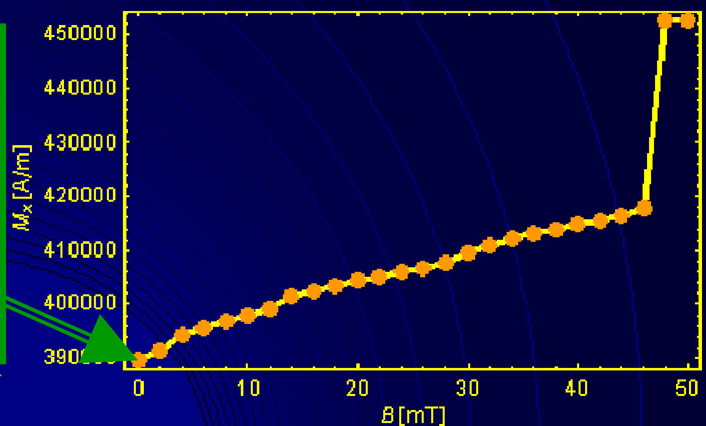




Charge distribution $\rho_s = \mu_0 \vec{n} \cdot \vec{M}$

Switching behaviour, 6 "coupled" trapeziums





- Strong stray field interaction within a chain
- small interaction between chains
- high shape anisotropy.
- Stable magnetic structure (for the single particle and the array)
- High coercivity

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Mikuszeit et al., J. Phys. C, **16**, 9037 (2004)
OOMMF freeware, M. Donahue and D. Porter, NIST

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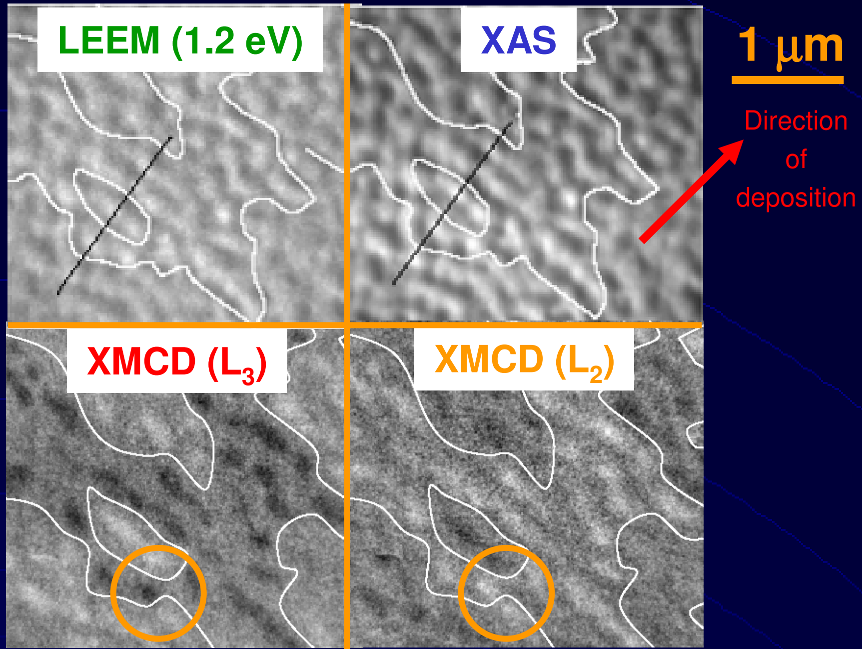
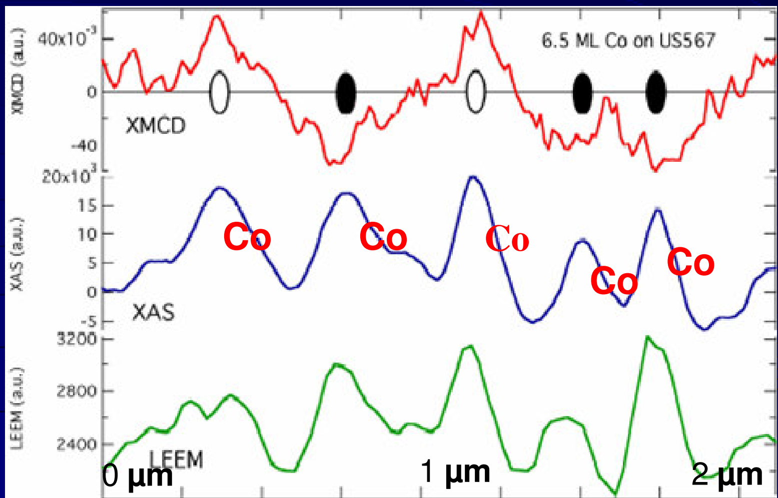
Imaging of dots (dipolar? coupled)



spontanious flip at room temperature



- **6.5 ML (1.5 nm) Co shadow deposited at 16º on $Si_{0.7}$ $Ge_{0.3}$**
- **Co near the top of the SiGe crystallites**
- **Magnetic contrast in the Co rich regions**
- **200 nm x 300 nm wide Co nanomagnets**
- **Micrometer size domains with correlated magnetization.**
- **Stronger coupling along the elongation of the nanomagnets.**
  (the dots coalesce?)

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A.M. Mulders et al., PRB **71**, 214422 (2005)

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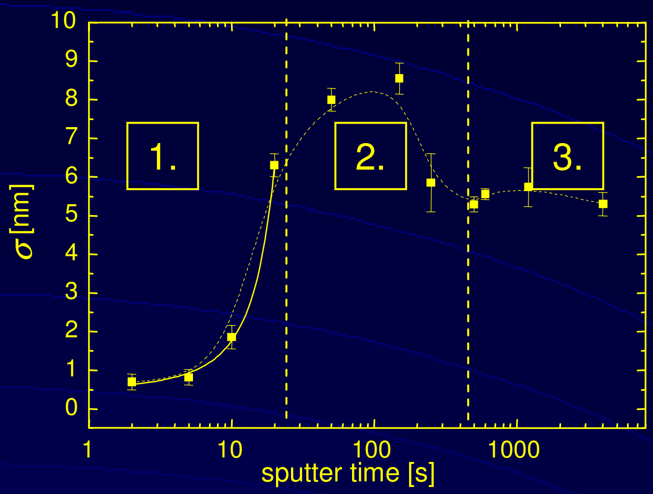
GaSb (roughening <-> smoothing)

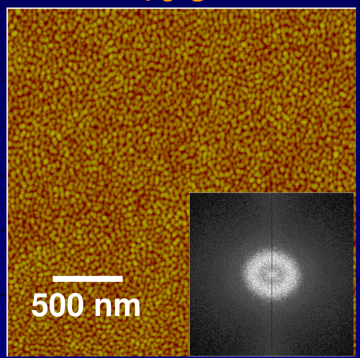


Three temporal regimes of dot formation dynamic:

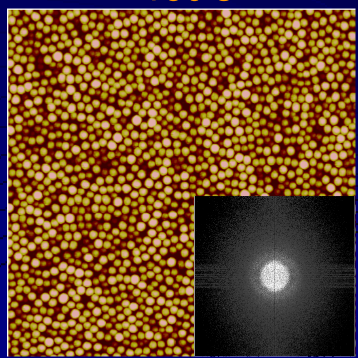
1. Exponential increase of roughness
2. Formation of a roughness maximum
3. Roughness Saturation at a lower value. Amplification of a characteristic wavelength, defect reduction with increasing time.

The behaviour is understood from and simulated with the stabilised Kuramoto Sivashinsky (KS) equation

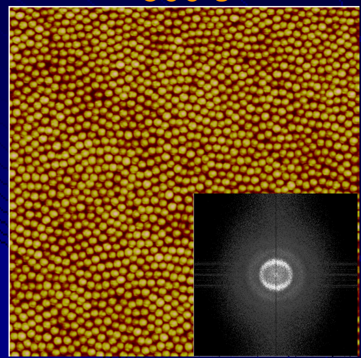
10 s



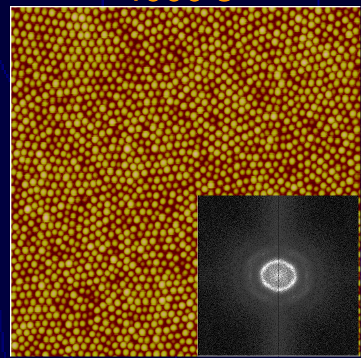
150 s



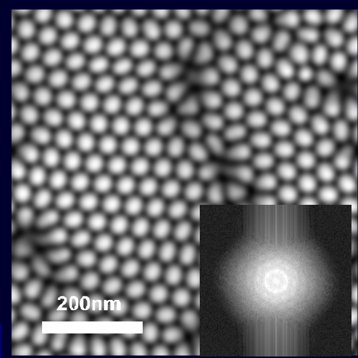
500 s



4000 s



simulation



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T.Bobek et al., PRB **68**, 85324 (2003)
Misbah et al., PRE **49,** 166 (1992)
Paniconi et al., PRE **56,** 2713 (1997)

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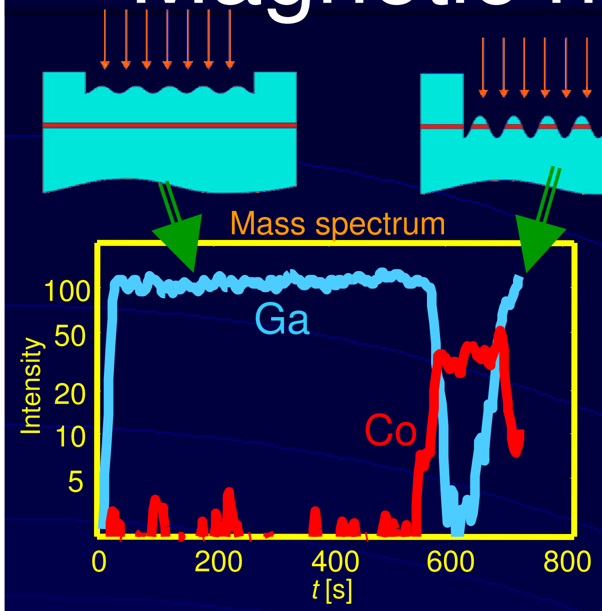
Magnetic nano discs

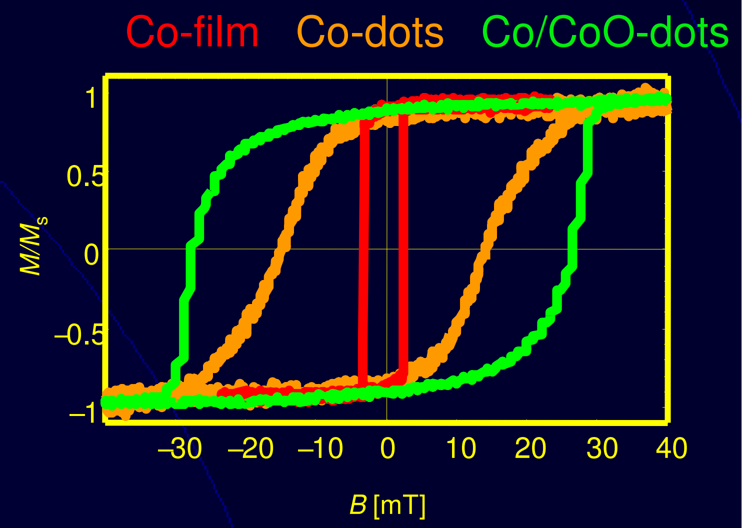


domain propagation

coupled
coherent rotaion

independent
coherent rotation?

Kerr signal of in-plane dots



Out-of-plane dots

Co/Pt multilayers: $K = K_{\text{bulk}} + \frac{K_{\text{surf}}}{h}$

$$K_{\text{surf}} \approx 27\,10^{-5}\ \frac{\text{J}}{\text{m}^2}$$

Elongated cylinders are

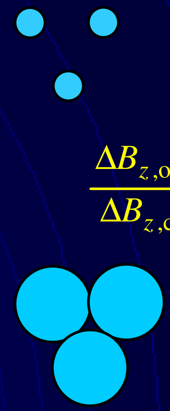
stabilised by: $K_{\text{shape}} = \frac{\mu_0}{2} M_s^2 S(\frac{2r}{h})$

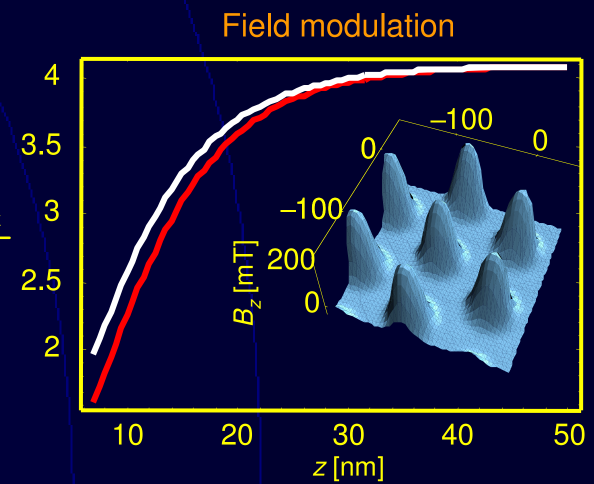
where $S(k) = 1 + \frac{4}{3\pi}k - \frac{{}_2F_1(\frac{5}{2},\frac{1}{2},2;\frac{k^2}{1+k^2})}{\sqrt{1+k^2}}$

r = 25 nm

h = 10 nm

h = 4 nm





J.-H. Kim et al., J. Appl. Phys. **80**, 3121 (1996)

Y. T. Millev et al., J. Phys D **36**, 2945 (2003)

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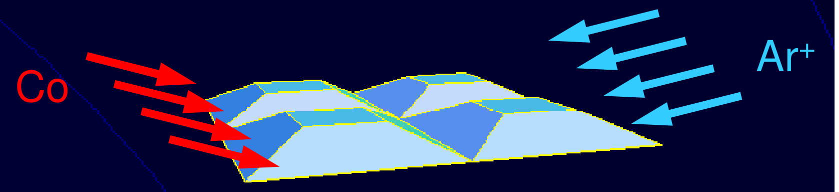
Conclusion / Outlook

- SiGe offers templates applicable for producing nano particles by shadow deposition
  - The coalescence could be cancelled by grazing incident sputtering



- The magnetic structures are stable
- The interaction can be approximated utilising a multipole expansion

- GaSb offers possibility to structure continuous films
- Independent dots (in-plane magnetised)
- Independent dots (out-of plane magnetised) soon.
- Disc size tuneable
- Structure may be improved by large scale pre-patterning