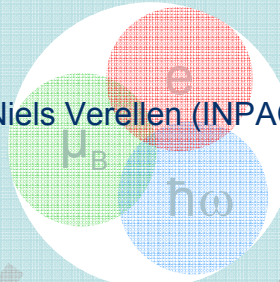
Guided vortex motion in nanostructured S/F hybrids



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Outline

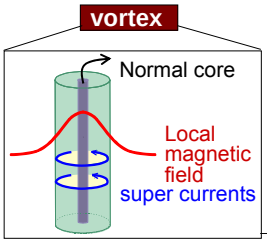
- Motivation
- In-plane magnetic dipoles
- Sample characterization
- Critical current
- Guided vortex motion
- Conclusion

Motivation

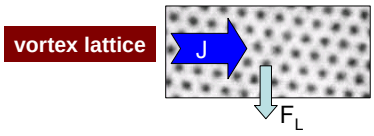
Perfect electrical conductivity
Magnetic field expulsion
} $T < T_c$, $I < I_c$, $H < H_c$

→ Thin films
High T_c superconductors
Type-II

• quantized fluxlines (ϕ_0)



• external field ~ vortex density
• repulsive interaction



• current → vortex motion

$$\mathbf{F}_L = \mathbf{J} \times \mathbf{\Phi}_0$$
$$\mathbf{E} = \mathbf{B} \times \mathbf{v}_d$$

Motivation

To modulate locally vortex distribution (magnetic fields) at will.

Enhance performance of fluxonic devices:
- Squid-based systems
- SC Thz emitters
- Predefined EM transmission

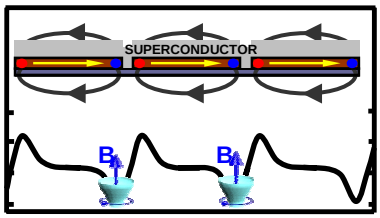
✓ Dissipationless current → **ARTIFICIAL PINNING POTENTIAL**
(e.g.: antidots, magnetic stray fields)

✓ Control the vortex dynamics → **ANISOTROPIC PINNING POTENTIAL**
• Rectification under ac-excitation
• Guidance under dc-excitation

lack of flexibility is a limiting factor

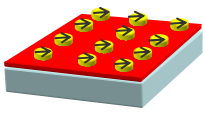
In-plane magnetic dipoles

- Pinning potential



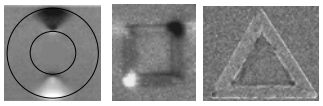
stray field $_{\perp}$

pinning potential



In-plane dipoles

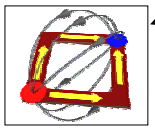
- Multiply connected structures



Co or Py

- Finite number of possible magnetic states
- Easy to switch between different states

Magnetic square microrings



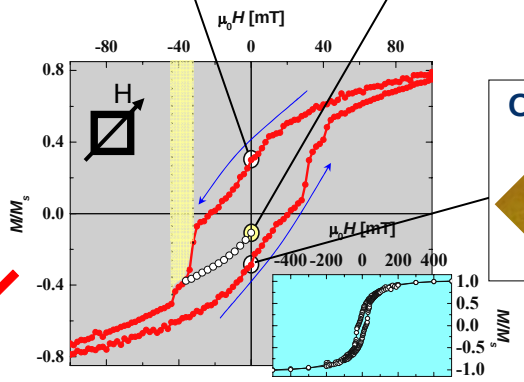
Shape anisotropy
+
Domain wall pinning

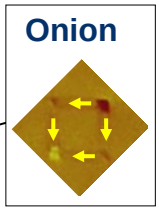
4 onion (dipolar) states
1 flux-closure state

Switchable stray field

Onion
Localized
out-of-plane
stray field

Flux-closure
Almost no
stray field





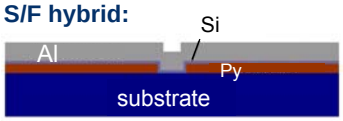
Onion

Sample characterization

Preparation:

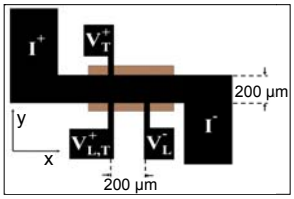
- e-beam lithography
- MBE

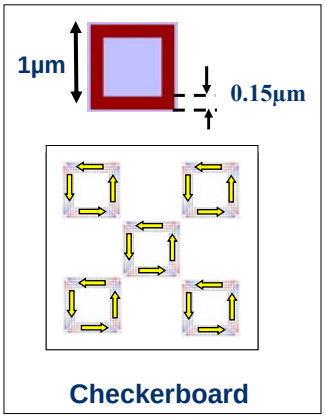
S/F hybrid:



S/F hybrid structure:

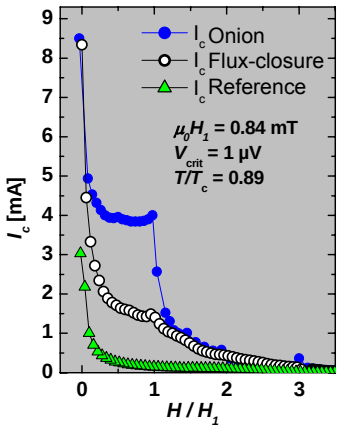
- **Si** substrate
- 25 nm **PERMALLOY**
- 5 nm **Si**
- 50 nm **Al** (type-II)





Checkerboard

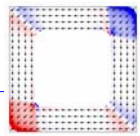
Critical current



(H$_1$ = 1 vortex / ring)

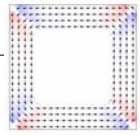
Onion state:

- efficient pinning



Flux-closure state:

- weak pinning



Controllable ON-OFF pinning potential

Guided vortex motion (GVM)

Isotropic pinning potential → $\bar{v} \parallel \bar{F}_L$

Anisotropic pinning potential → $\bar{v} \not\parallel \bar{F}_L$?

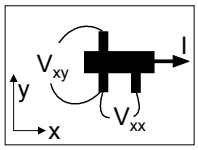
$\bar{E} = \bar{B} \times \bar{v}_d$

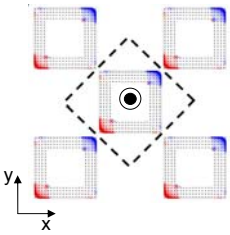
$V_{xx} \sim E_x = -B\, v_y$
$V_{xy} \sim E_y = B\, v_x$

Measure V_{xx} and V_{xy}

↓

vortex motion direction

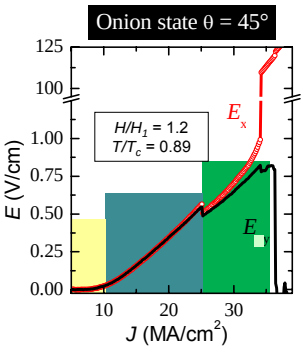


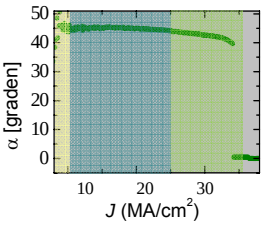


Influence on vortex dynamics?

- local symmetry?
- lattice geometry?

Guided vortex motion

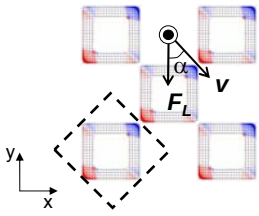




$E_x = E_y = 0$ → vortices remain pinned

$E_x \approx E_y$ → GVM α = 45°!

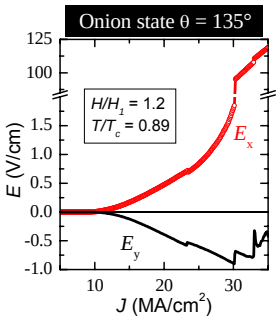
$E_x \neq E_y$ → alignment of **v** and $\mathbf{F_L}$

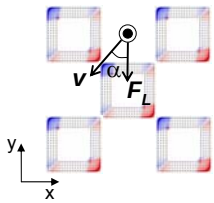


GVM as a concequence of an anisotropic pinning force

GVM along high symmetry axis of the magnetic pinning lattice

Guided vortex motion: local symmetry

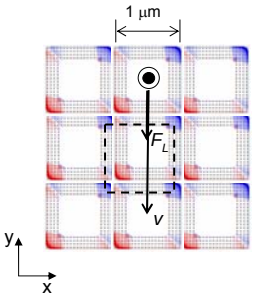




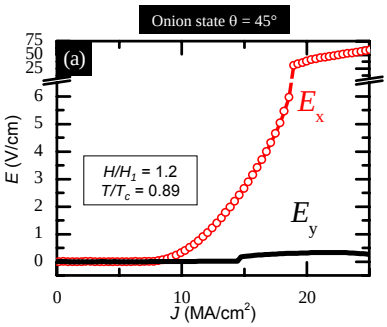
sign reversal indicates relevance of local symmetry of the pinning centra

GVM resulting from magnetic landscape not topographic corruption

Guided vortex motion: lattice geometry



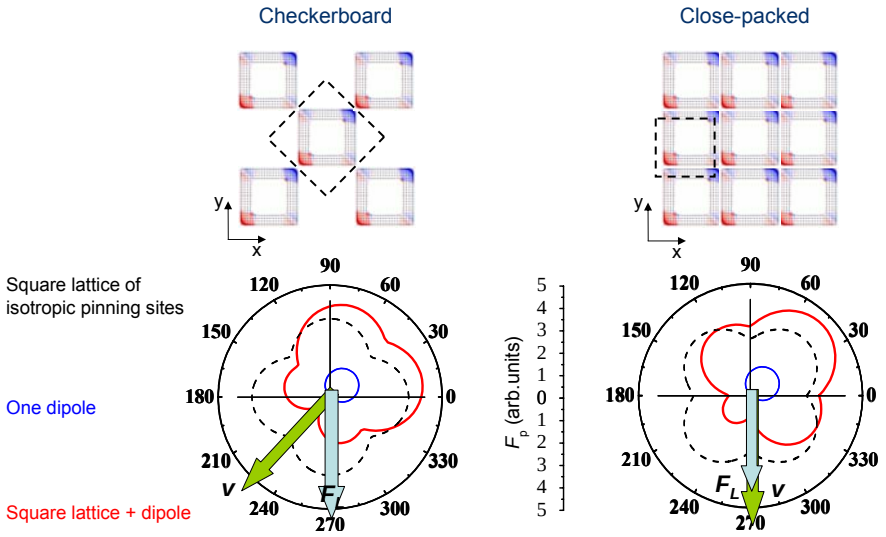
- square lattice
- nearly point-like dipoles
- oriented at 45° away from the current direction
- ***unit cell rotated by 45°***



clear relevance of the dipole lattice unit cell orientation

Vortex motion along high symmetry axis of the magnetic pinning lattice

Guided vortex motion: pinning force



Conclusion

Square magnetic ring structures allow a <u>simple</u> and <u>controlled</u> external <u>manipulation</u> of:

1. **strength of the pinning potential**

<u>Dipolar state</u>
efficient pinning

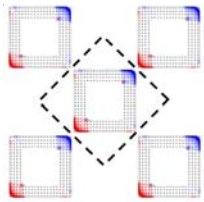
<u>Flux-closure state</u>
weak pinning

2. **anisotropy of the pinning potential**

- Anisotropy is capable of directing vortex motion // F_L (α = 45°)
- Multiple states of the rings allow to change this GVM
  → importance of local symmetry
- Also the orientation of the square lattice unit cell is important
  → importance of lattice geometry

Thanks for your attention

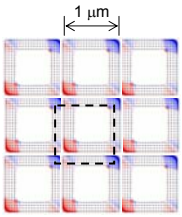
Parameters



ξ(0) = 130 nm

$T_{c,onion}$ = 1.356 K

μ0H1 = 0.84 mT

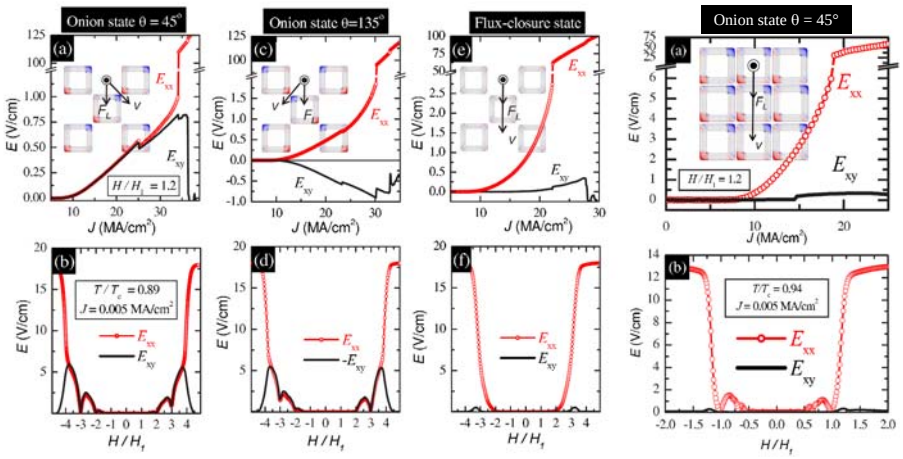


ξ(0) = 138 nm

$T_{c,onion}$ = 1.274 K

μ0H1 = 1.664 mT

Guided vortex motion: H>H_1



By keeping cst current density and increase magnetic field we can realize the same dynamic behavior.

Guided vortex motion: $H \gtrapprox H_1$

$H > H_1$

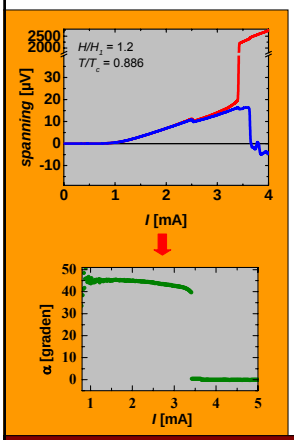
Interstitial vortices

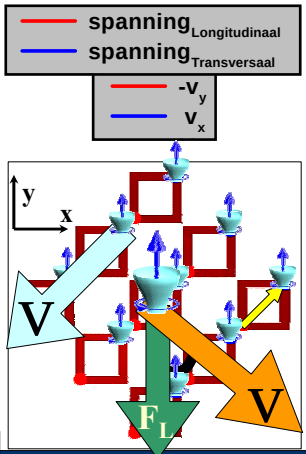
DIPOOL
θ =45°

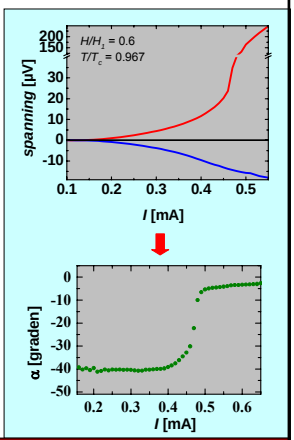
$\overline{m}$

$H < H_1$

Free pinning sites







GVB α = + 45°

GVB α = - 45°