SAND2009-4793C

Locally-controlled domain microstructures in bismuth-iron-garnet films for magneto-optical current sensors

SPIE Optics+Photonics

August 4, 2009

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This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

NNSA National Nuclear Security Administration

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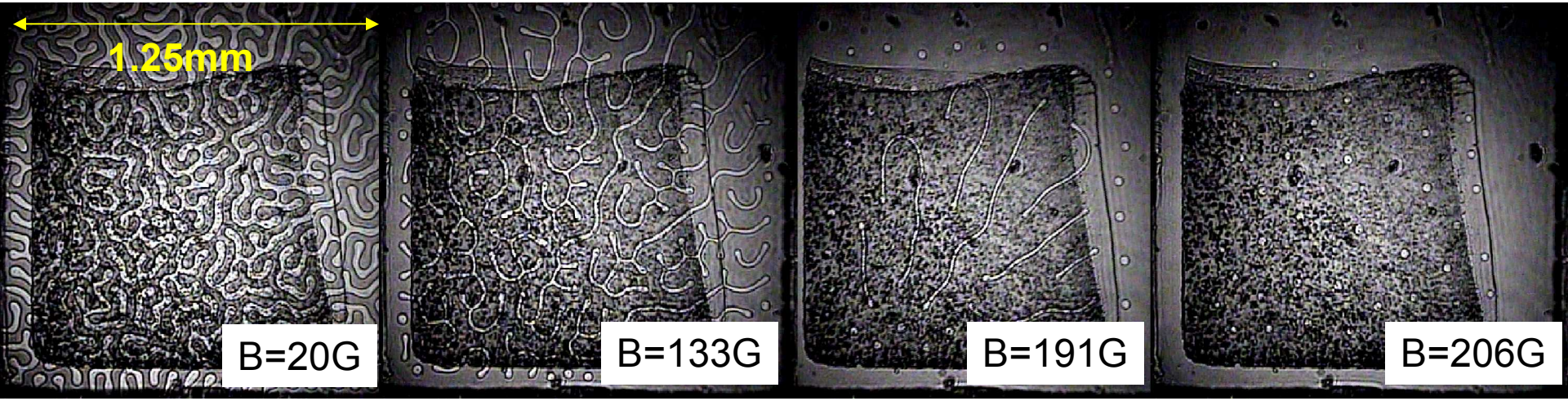
Outline

- Bismuth Iron Garnet (BIG) Introduction
  - Magnetic and magneto-optical properties
  - Domain Motion
- Magnetic field sensing application
- Using BIG as a magnetic sensor
- Sensor results
- Local domain phase control

Introduction to Bismuth Iron Garnet

- Ferrimagnetic material used in Faraday isolators
- Roughly $Bi_3Fe_5O_{12}$ (+Y, Al, Ca)
- Grown as ~450 μm thick epitaxial film on GGG substrate (substrate removed)
- Develops easy magnetization direction perpendicular to film surface, forms stripe/bubble domains to minimize total energy



Increasing external B-field

Stripe phase

Bubble phase

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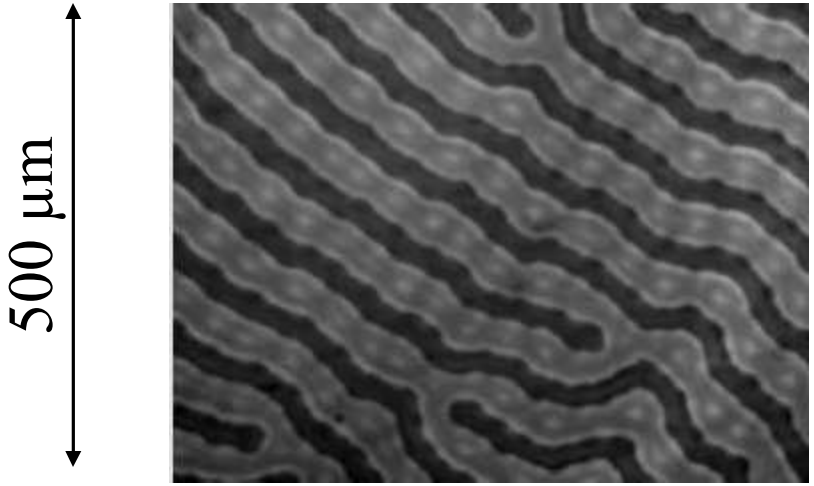
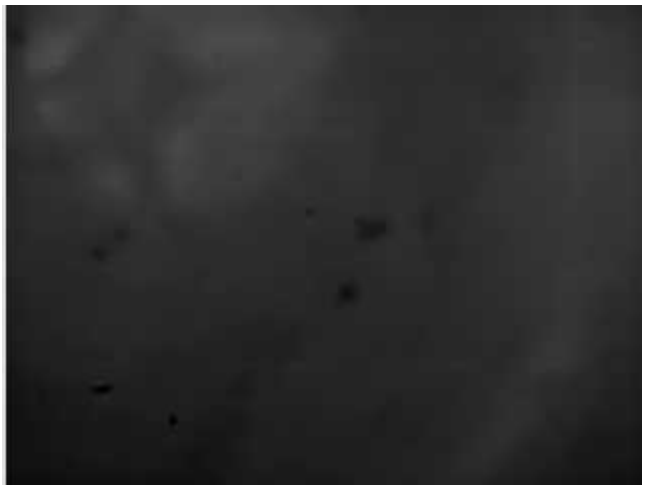
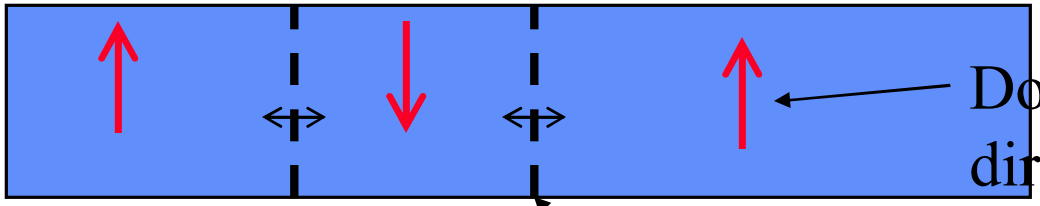
Domain motion under changing B





Increase B
0G to 500G

Decrease B
500G to 0G



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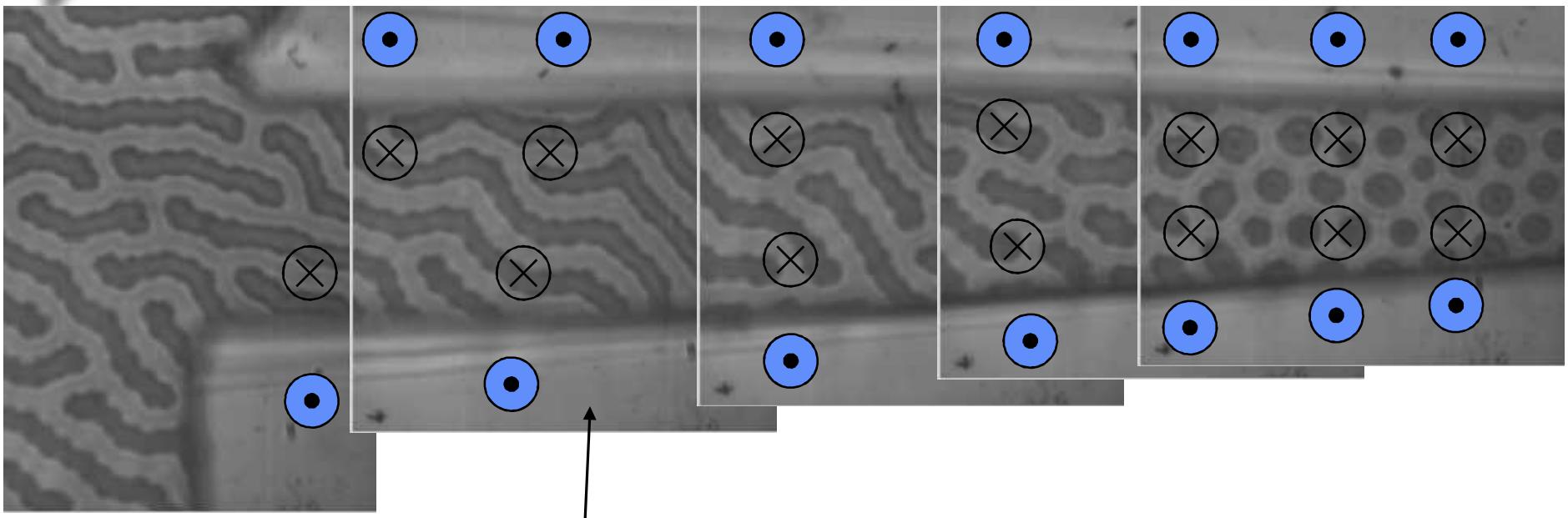
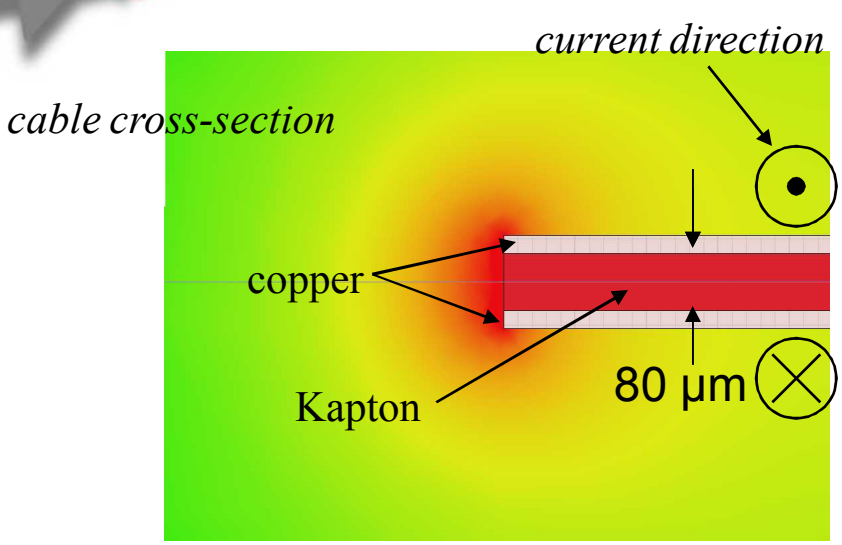
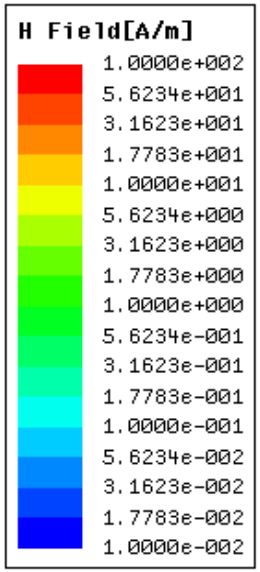
Controlling Domain Location (B_{ext}=0)

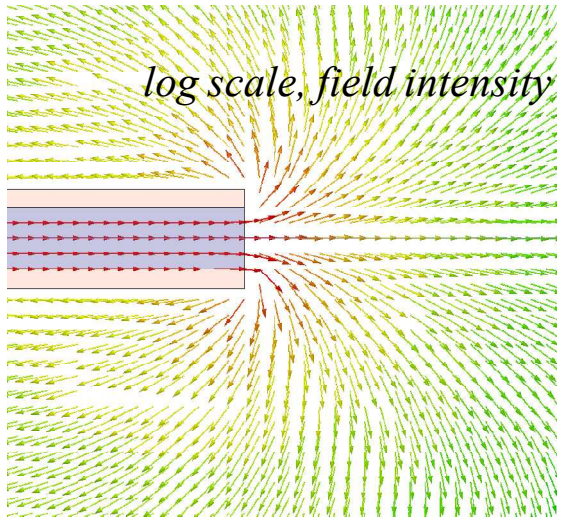


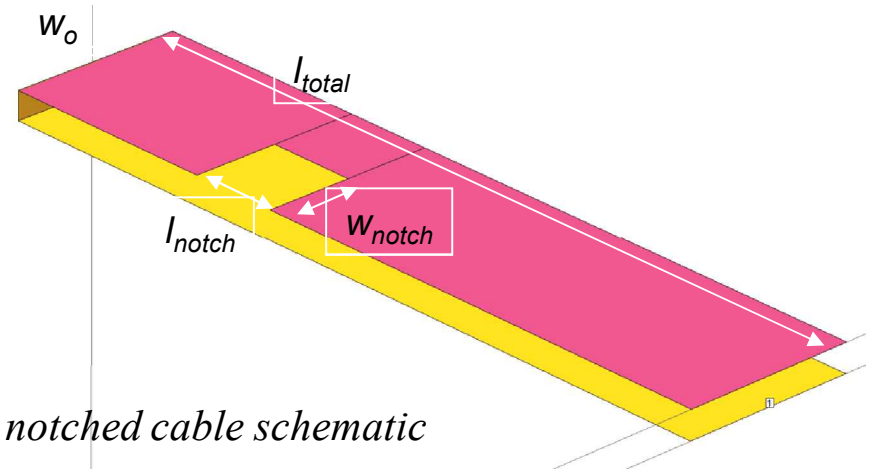
Deposited SmCo bias magnet
Magnetized out-of-plane

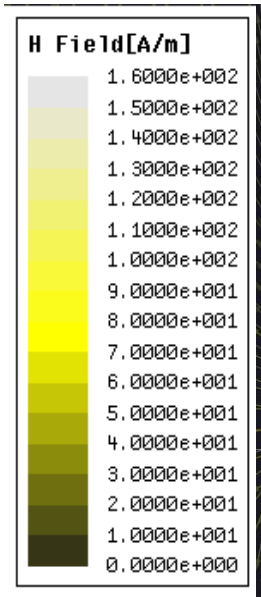
Application:
Measuring current transients in high current cables



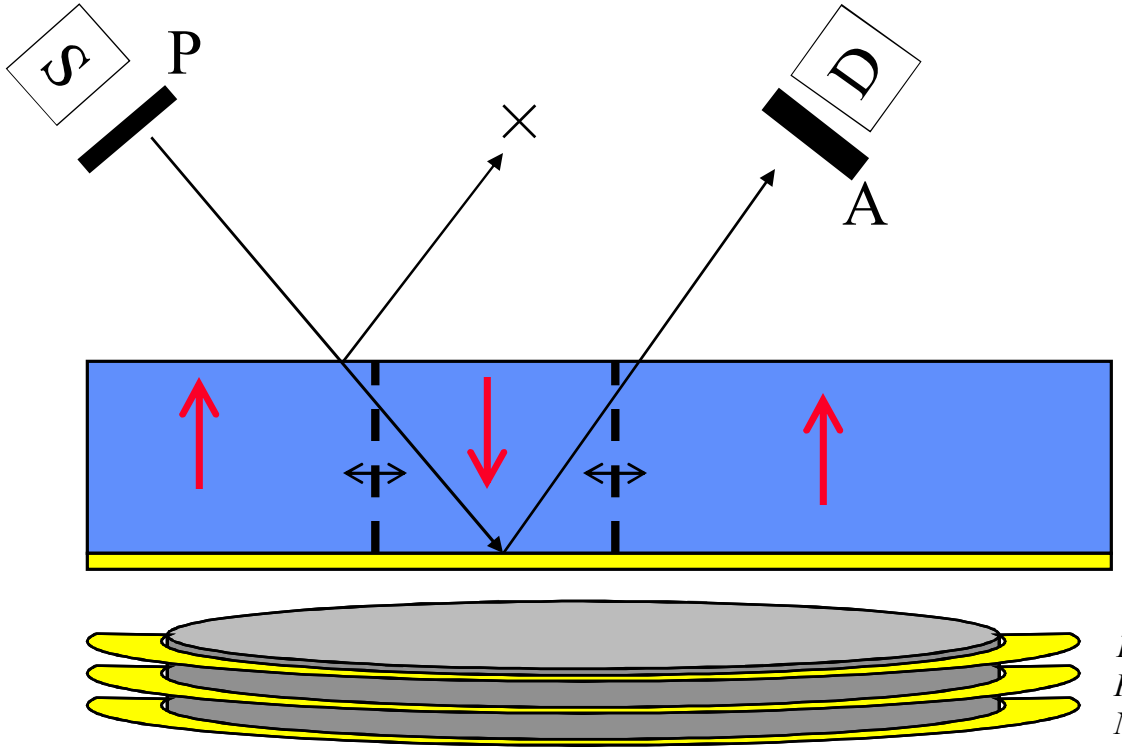








Field Sensing by Domain Size



100-turn coil
Field strength to ~1000 G
Notched cable field to ~6000 G

External magnetic field changes domain size
- Changes polarization state of beam reflected from back surface
- Changes intensity at detector
- Signal increases for external field parallel to domain, decreases for antiparallel orientation – not just magnitude sensitive

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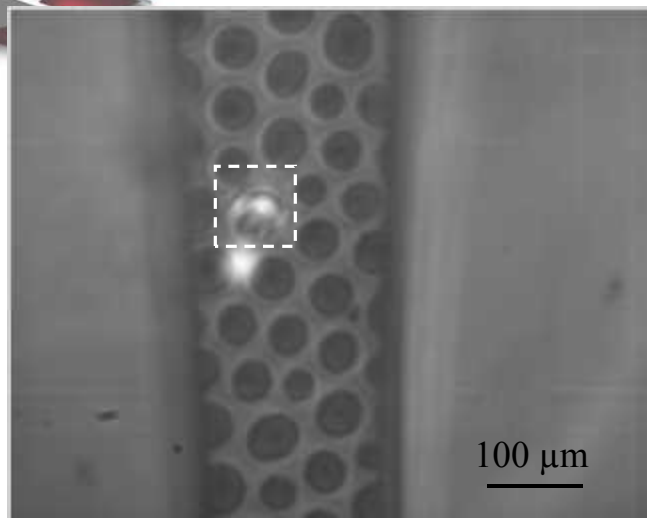
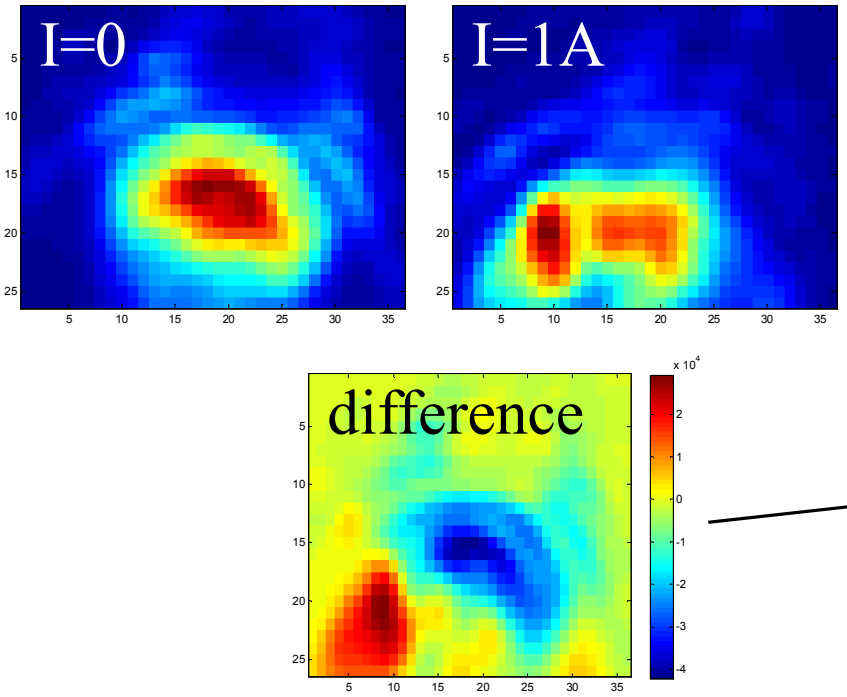
Probe beam results



Change in light scattering when probing a single bubble highly variable, difficult to reproduce



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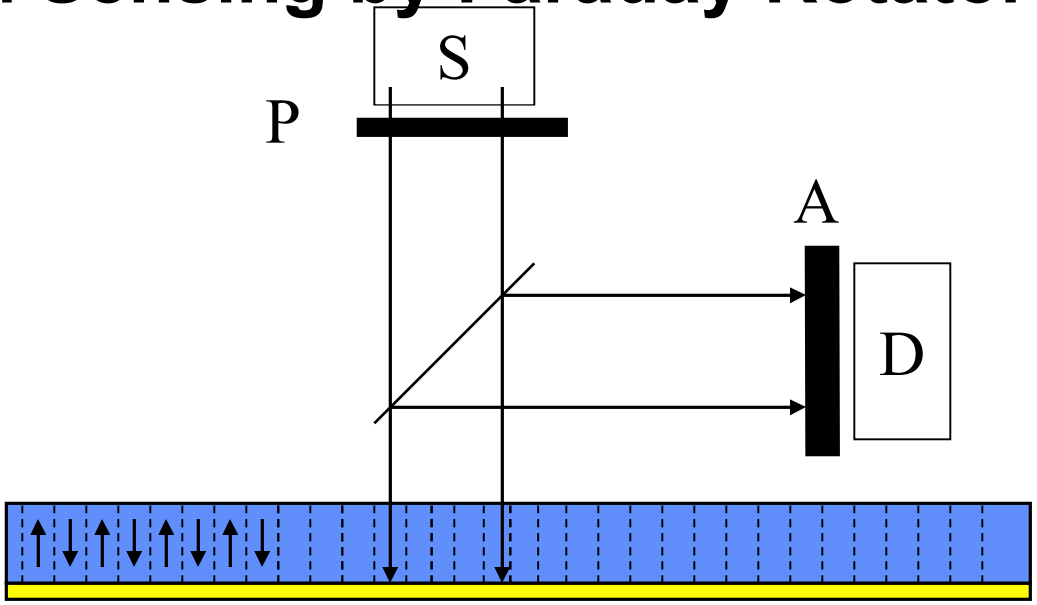
Field Sensing by Faraday Rotator Effect



External magnetic field changes domain size

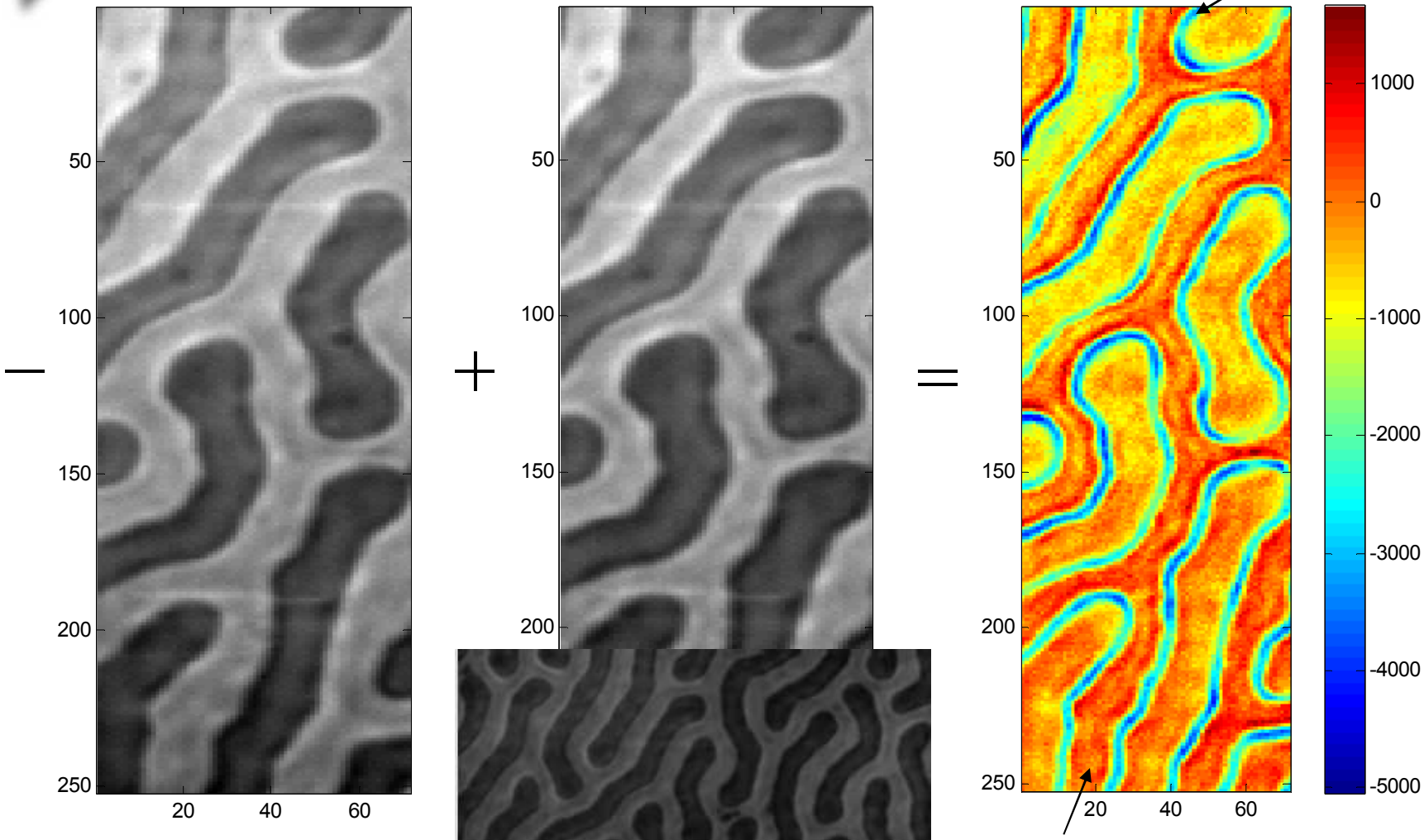
- Change in intensity due to change in area of domains aligned with external field
- Signal increases for external field parallel to domain, decreases for antiparallel orientation – not just magnitude sensitive

Stripe phase imaging

No field

Coil @ 1A

dark stripes expand and get slightly darker



bright stripes shrink but get slightly brighter

0 – 0.75A pulse video

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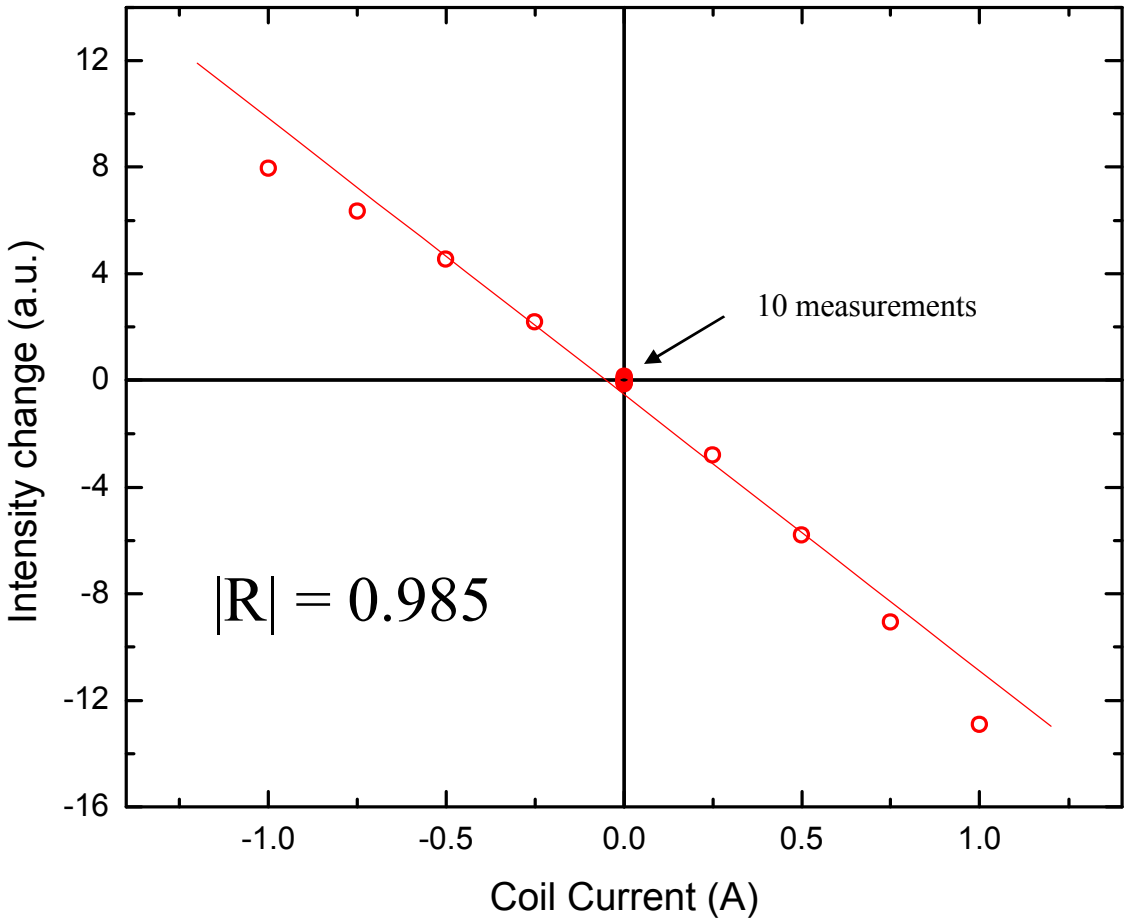
Stripe phase imaging results



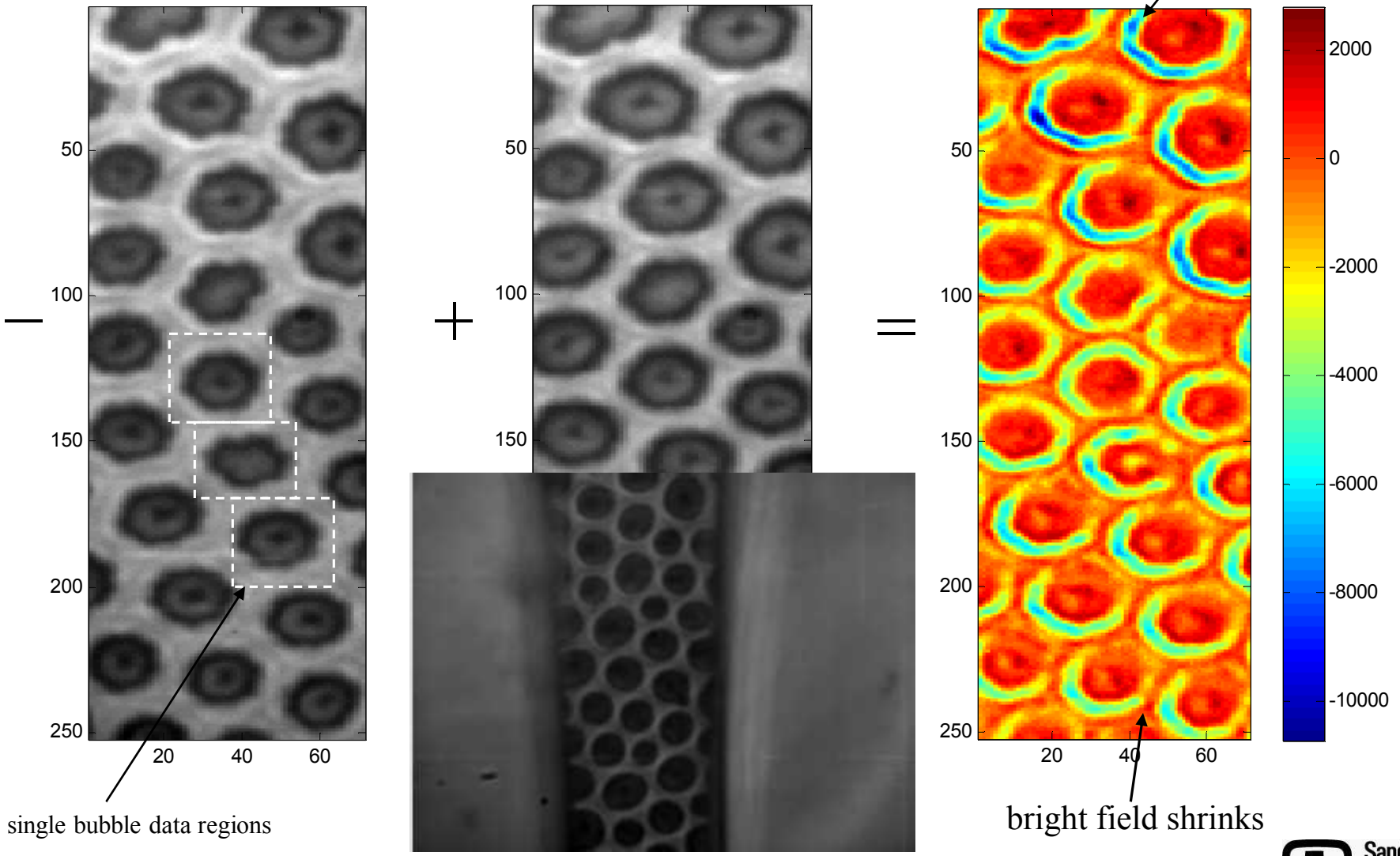
Not very linear averaging over ~500x140 micron stripe area

Bubble phase imaging

No field

Coil @ 1A

dark bubbles expand but get slightly brighter



single bubble data regions

bright field shrinks

0 – 0.75A pulse video

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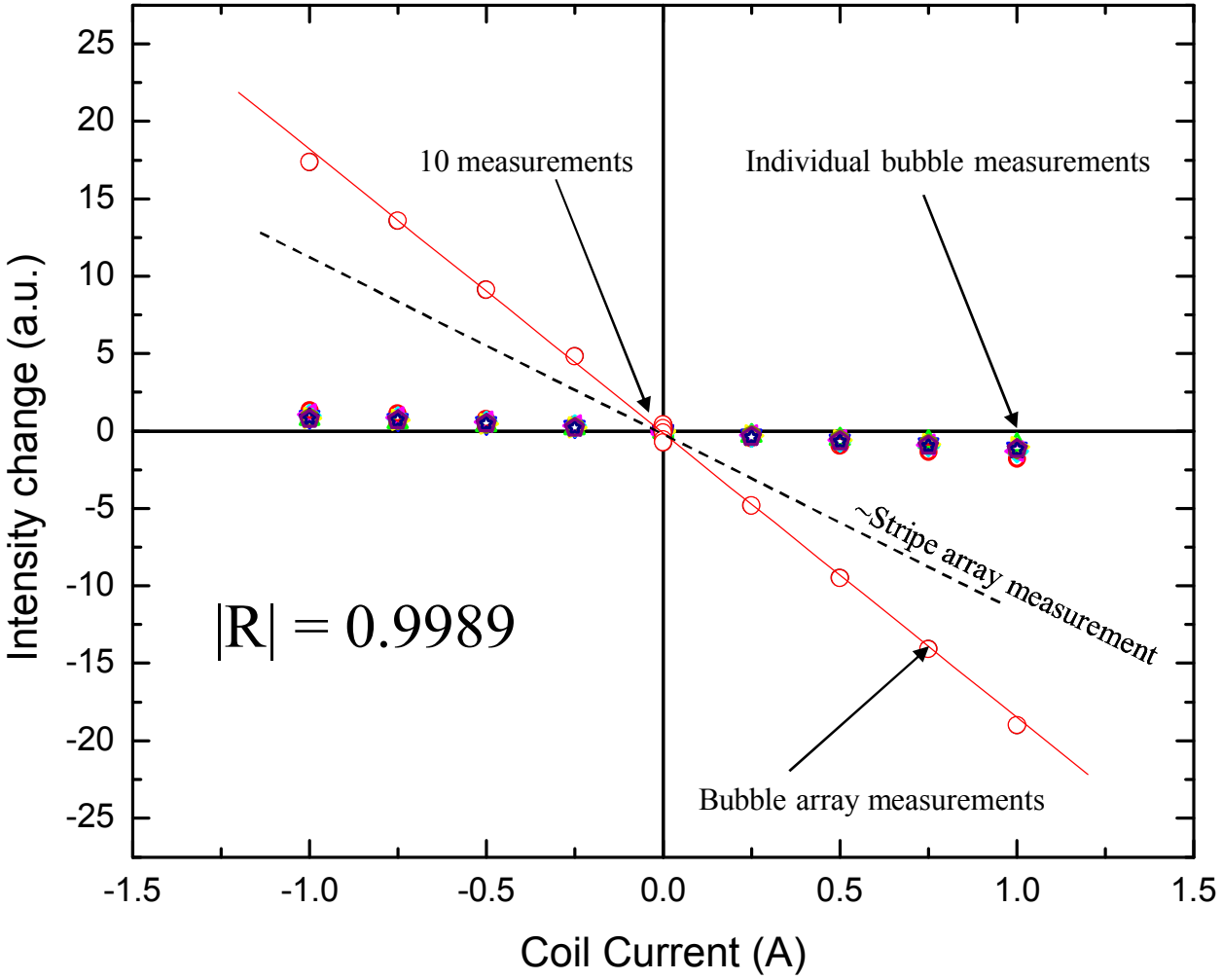
Bubble phase imaging results



Improved linear averaging over ~500x140 micron bubble area

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Summary

- Optical detection of domain motion in BIG films was used to sense a magnetic field
  - Collimated probe beam gave poor results due to sensitivity of beam scattering to alignment with bubble
  - Stripe domain ensemble average gave more linear results
  - Bubble ensemble average was most linear
    - May be due to improved linearity in a particular portion of the magnetization curve
- Integrated SmCo thin film magnet used to influence bubble domain formation
  - next step is to engineer SmCo magnet shape to further define/control domain motion
    - linearization, reproducibility, sensitivity