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Title: Femtotesla atomic magnetometry in a microfabricated vapor cell

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Houston, Texas

Los Alamos
NATIONAL LABORATORY
EST. 1943

Abstract:

Chip-scale atomic magnetometers developed at NIST are based around microfabricated vapor cells, consisting of an etched hole in a silicon wafer and anodically bonded pyrex windows. The vapor cells typically contain ^{87}Rb atoms and several atmospheres of nitrogen buffer gas. Using a 3x2x1~mm vapor cell we have demonstrated a magnetometer with sensitivity better than 5 $fT/Hz^{1/2}$. The magnetometer is operated in the spin-exchange relaxation free (SERF) regime and uses two perpendicular light beams: a circularly polarized pump beam and an off-resonant linearly polarized probe beam. Magnetic fields are detected by analyzing the polarization direction of the probe beam. The measurement volume for this result is 1~mm^3, defined by the overlap of the pump and probe beams, giving a magnetic field energy resolution of $V B^2 / 2 \mu_0 = 95 \hbar$, within about a factor of two of the best result for an atomic magnetometer [1]. Achieving this sensitivity level in a millimeter scale vapor cell compared to larger cells requires special consideration of thermal magnetic noise due to the electrical conductivity of the silicon cell body and condensed alkali atoms on the cell walls.

[1] H. B. Dang, A. C. Maloof, and M. V. Romalis, arXiv:0910.2206

Femtotesla atomic magnetometry in a microfabricated vapor cell

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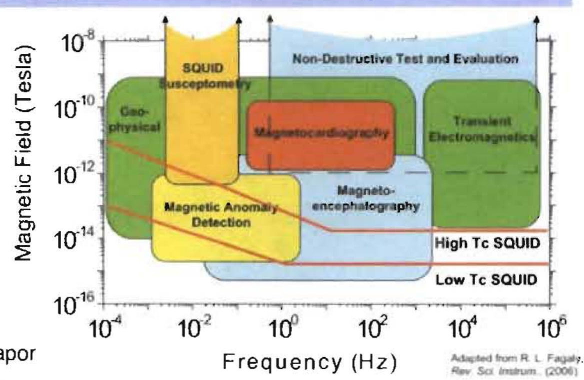
NIST
National Institute of Standards and Technology
U.S. Department of Commerce

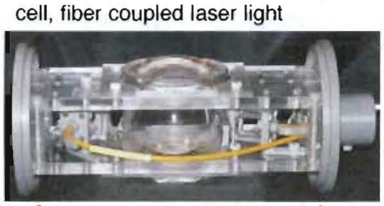
Chip Scale Atomic Magnetometer (CSAM)

Atomic magnetometers with fT sensitivity can potentially be a non-cryogenic alternative to SQUIDs



Adapted from R. L. Fagaly, Rev. Sci. Instrum. (2006)

Cs magnetometer with glass vapor cell, fiber coupled laser light



20 cm

S. Groeger, PhD. thesis, Univ. Fribourg (2005)

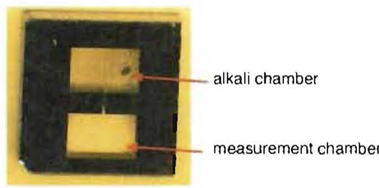
Chip scale Rb magnetometer on a fingertip

Microfabricated vapor cells

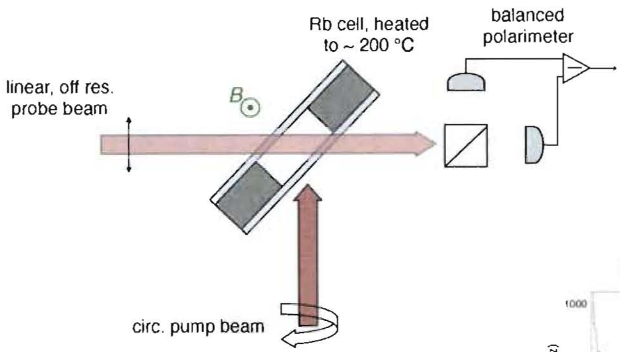
Microfabricated vapor cells:
cavity etched in a silicon wafer,
pyrex windows anodically bonded
after filling with ^{87}Rb and 1-5 atm N_2

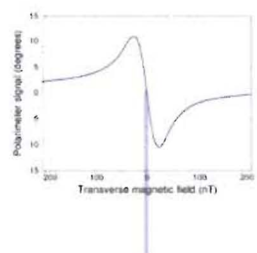
single chambered cell:

dual chambered cell:

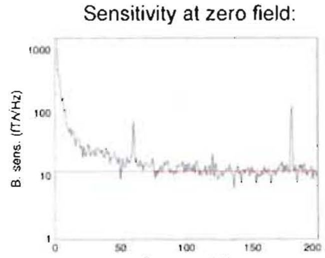


Dual beam SERF magnetometer

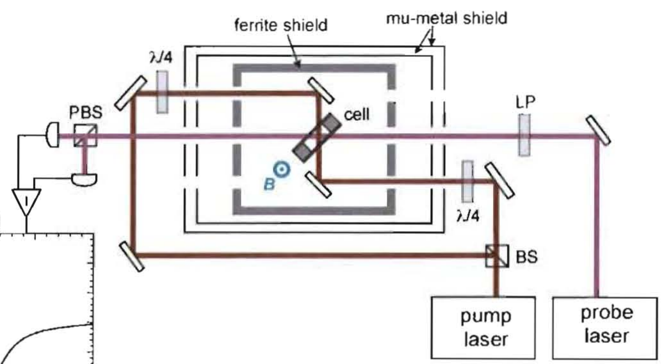


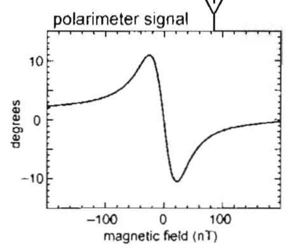


Sensitivity at zero field:

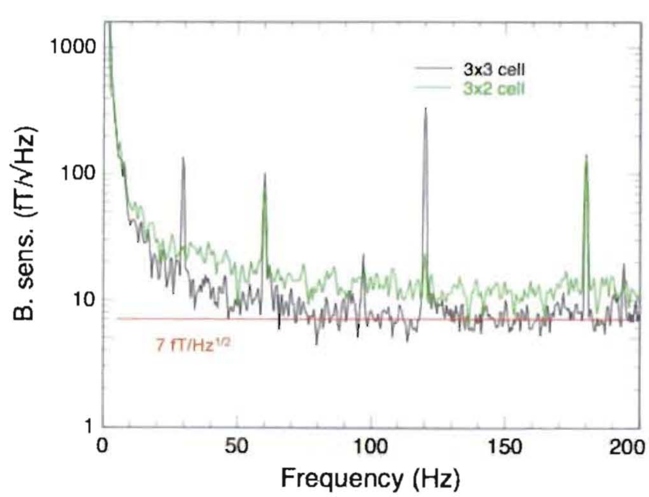


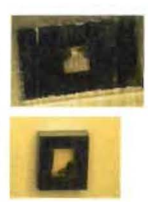
Experimental setup



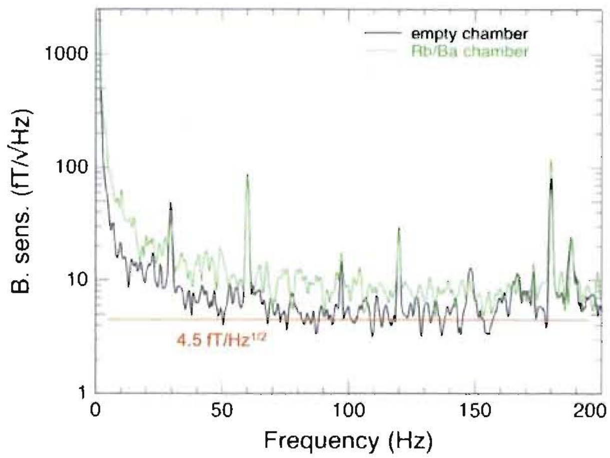


Single chamber cell sensitivity





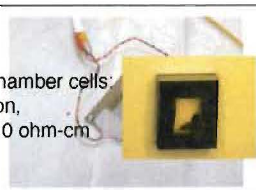
Dual chamber cell sensitivity



Thermal magnetic noise

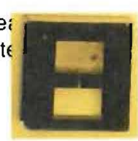
source	noise est. (fT/Hz$^{1/2}$)
Rb film (1 nm thick)	3
Rb droplet (100 μm diam.)	7
➡ Silicon (ρ ~ 5 ohm-cm)	5
➡ ITO slide (heater)	3
➡ heater connections (conductive epoxy, busbars)	2
ferrite shield (@ 100 Hz)	0.4
mirrors	0.1

single chamber cells:
CZ silicon,
ρ ~ 1– 10 ohm-cm



can switch to optical hea
redesign electrical heate
reduce silicon noise

dual chamber cells:
FZ silicon,
ρ ~ 8000 ohm-cm



Magnetometer energy resolution

$$\delta\epsilon = \frac{(\delta B)^2 V}{2\mu_0}$$

D. Robbes, Sens. and Act. A 129, p. 86 (2006)

- active volume = overlap region of pump/probe beams
- Best atomic magnetometer result (Dang, Maloof, Romalis – arXiv:0910.2206):
  - 0.16 $fT/Hz^{1/2}$, active volume = 0.45 cm^3

$$\delta\epsilon = 44\,\hbar$$

- Our current result:
  - 4.5 $fT/Hz^{1/2}$, active volume = 1 mm^3

$$\delta\epsilon = 77\,\hbar$$

Summary

- SERF magnetometry combined with a MEMS vapor cell allow SQUID-like sensitivity in non-cryogenic sensor
- 4.5 $fT/Hz^{1/2}$ sensitivity with a 1 mm^3 active volume
- Reaching this level of sensitivity requires careful control of Johnson noise from Rb, silicon, etc.
  - less of an issue for larger cells
- Future plans:
  - change heating method to reduce noise further
  - build fiber-coupled sensor head (~ 1 cm^3)
  - multiple sensors for gradiometry

See also: Svenja Knappe, "Chip Scale Atomic Magnetometers," Saturday 9:00

APS Meeting Registration

Meeting: Division of Atomic, Molecular and Optical Physics

Dates: 05/25/2010 - 05/29/2010

Location: 1200 Louisiana Street
Houston, TX 77002

You have successfully registered for the meeting. Your confirmation number is: 104614.

Contact Information:

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Phone: (505) 664-0837
Email: wcgriff@lanl.gov

Order Detail:

	Description	Qty	Price	Amount
Primary Item:	Full Registration	1	$500.00	$500.00
	Banquet Ticket (Included in above price.)	1	$0.00	$0.00
			Total:	**$500.00**

Payment Detail:

Invoice Number: 1129082

Amount: $500.00

Payment Date: 04/29/2010

Credit Card: ****6681

- An email confirmation will be sent.
- This page also serves as your receipt.
- If you need assistance at any time regarding your meeting registration, please contact the meeting registrar at: registrar@aps.org or 301-209-3289