Magnetic lasers

Tim Verhagen

Groupmeeting, 10 march 2010

Partners

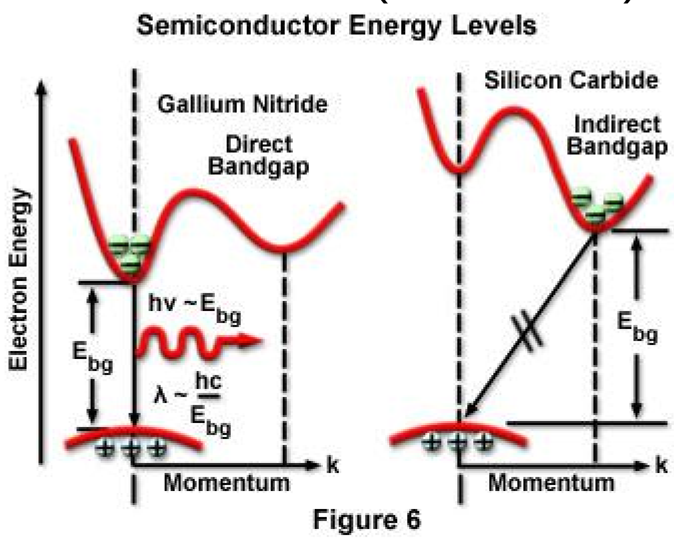
- KTH – Vladislav Korenivski
- Univ. Konstanz – Elke Scheer
- Göteborg U – Robert Shekhter, Anatoli Kadigrobov
- ILTPE – Igor Yanson, Yuri Naidiuk

Contents

- **Why magnetic laser**
- Zeeman based laser
- Exchange splitting based laser
- Set up
- Outlook

Spin flip laser

Semiconductor (laser diode)



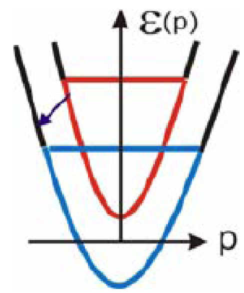
$\Delta k = 0$

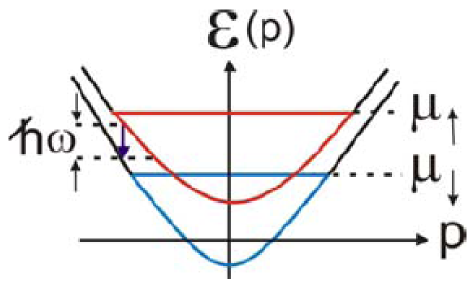
photon

$\Delta k \neq 0$

phonon

Magnetic (spin flip laser)





$\Delta k \neq 0$

magnon

↓

High frequency oscillators

$\Delta k = 0$

photon

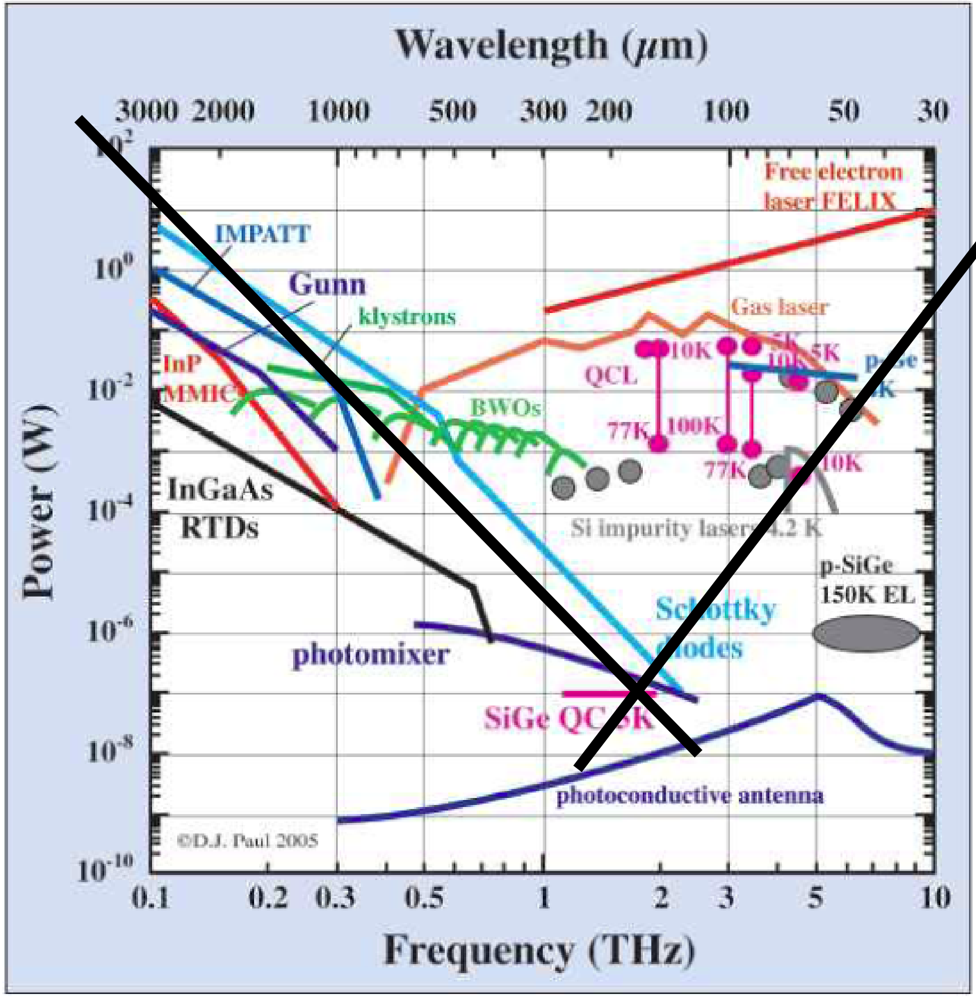
↓

High frequency lasers

Why magnetic lasers?

Electronics

$$P \propto \frac{1}{\nu^4}$$



Optics

$$k_b T < h\nu$$

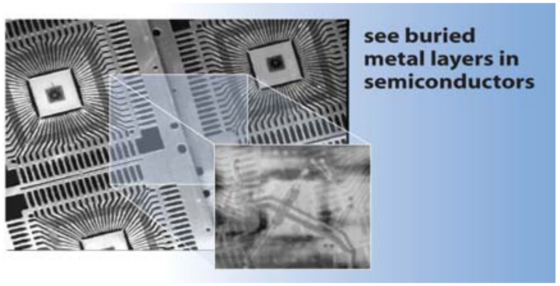
1 THz = 4meV

1 THz = 48K

1 THz = 33cm-1

1 THz = 0.3mm

What can you do with THz?



Quality control

Se

ng

non-conducting materials

netrate water and metals

Biological imaging

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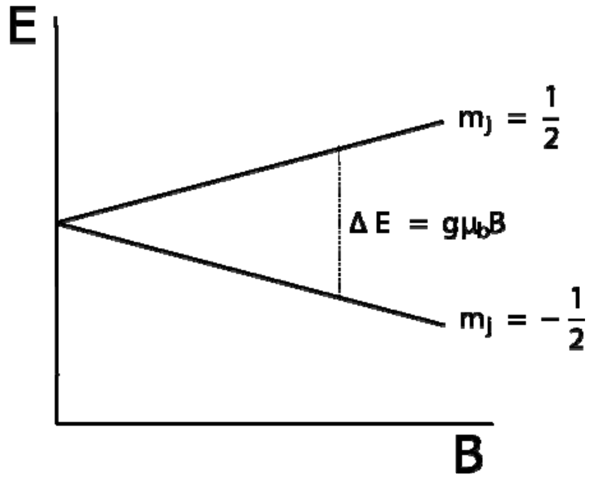
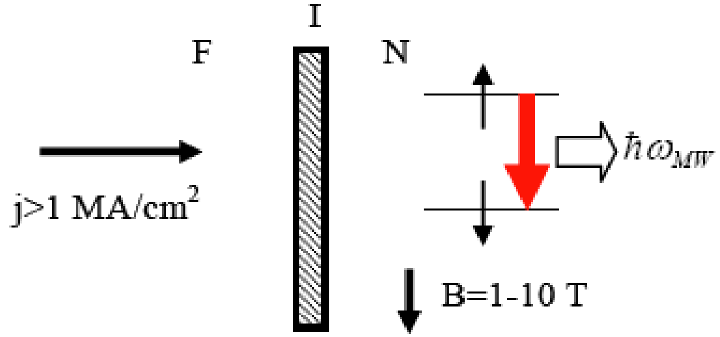
Zeeman split transition





Zeeman effect

$$h\nu = g\mu_B m_s B$$
$$\nu = 0.007 g B [\mathrm{THz}]$$

Devices, Majority F

If coercive field of F is (much) bigger than applied field

($SmCo_5, AlNiCo, Nd_2Fe_{14}B$)

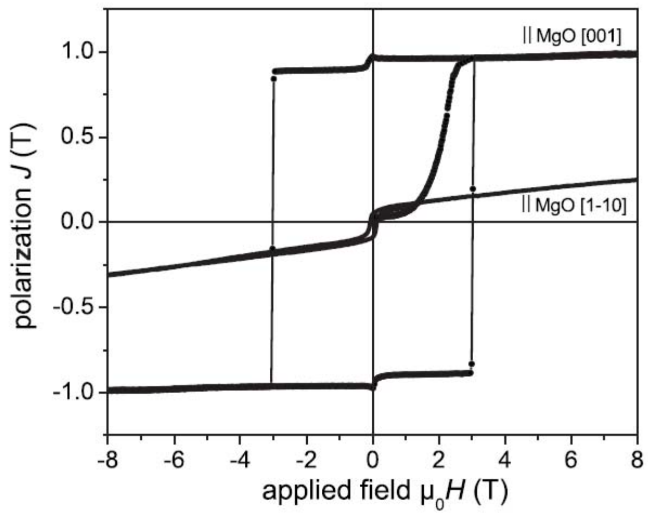
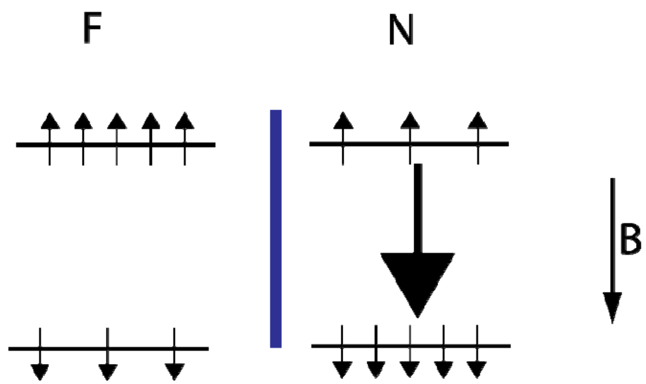
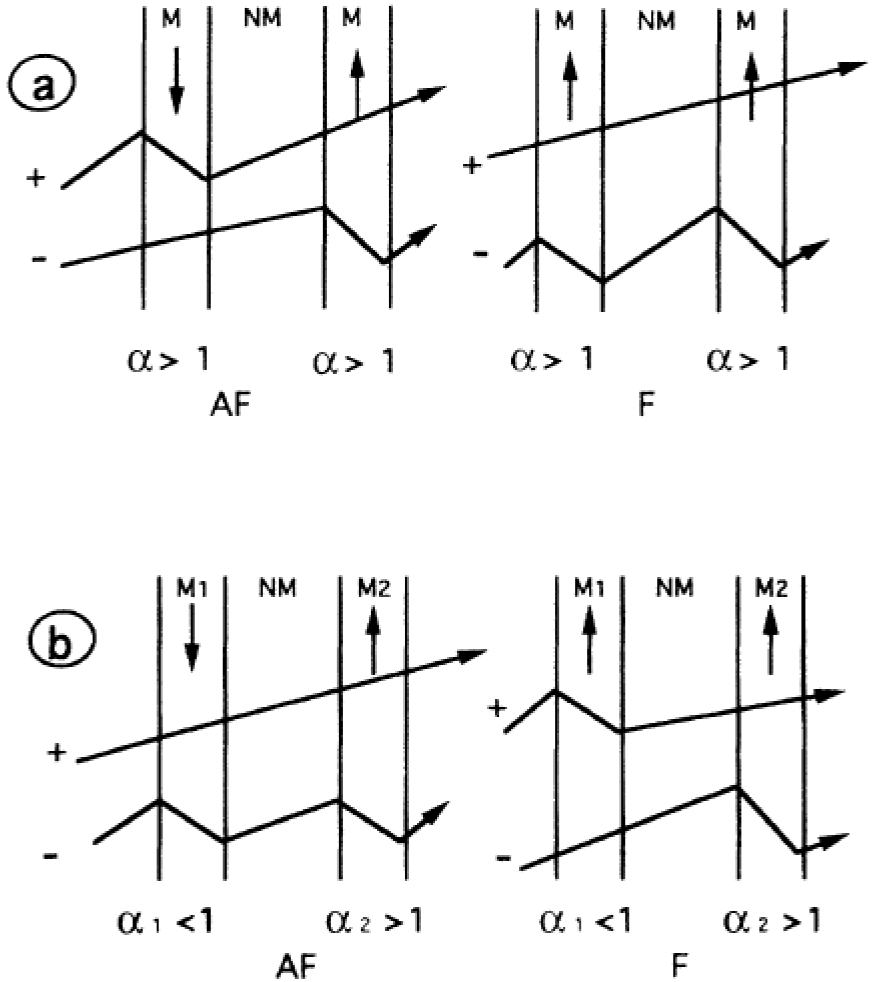


FIG. 2. Magnetic hysteresis of a $SmCo_5$ film measured along the easy magnetization axis (||MgO[001]) and along the in-plane hard axis (||MgO[1−10]).



PRB 77 104443

(Inverse) GMR



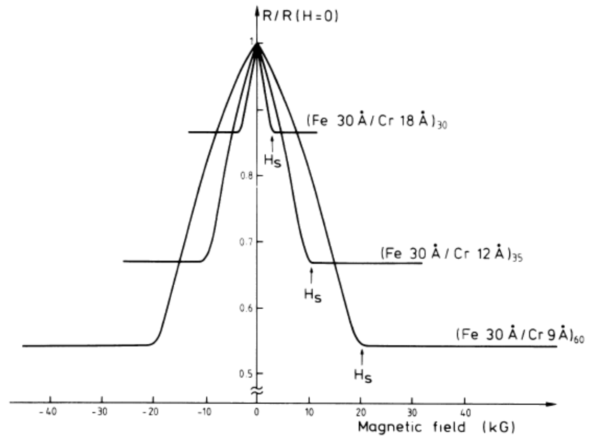


FIG. 3 Magnetoresistance of three Fe/Cr superlattices at 4.2 K. The current and the applied field are along the same [110] axis in the plane of the layers.

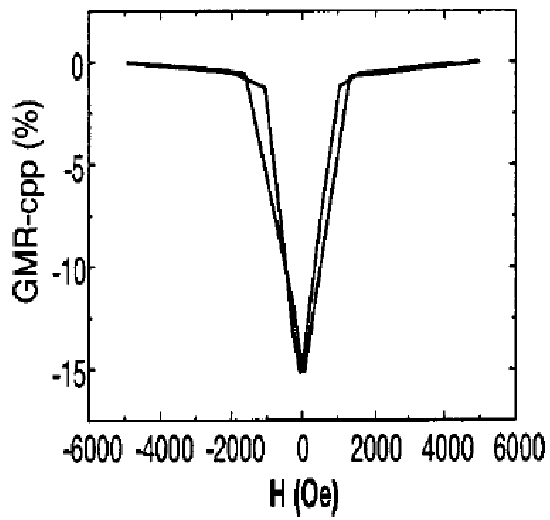


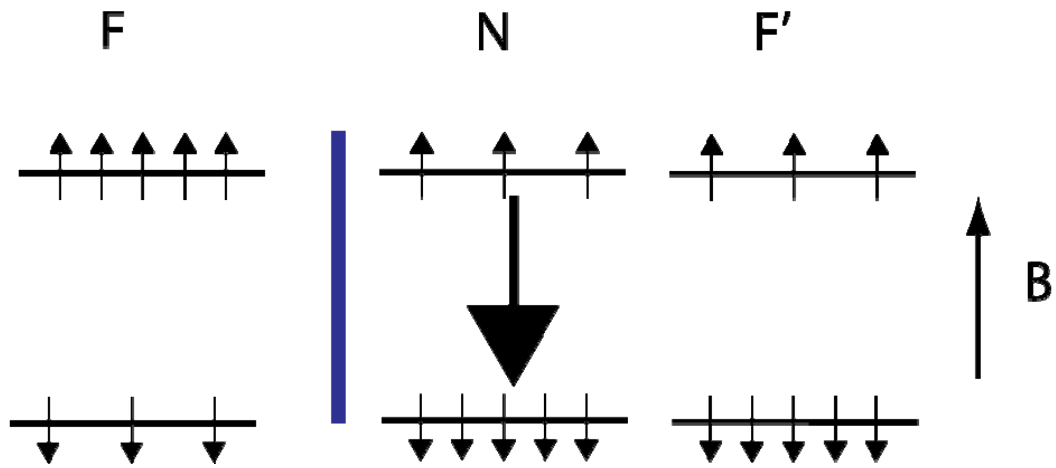
FIG. 16. Inverse GMR curve of a $[FeCr\ 30\%(5\ \mathrm{nm})/Cr(1.1\ \mathrm{nm})/Py(8\ \mathrm{nm})/Cr(1.1\ \mathrm{nm})]\times 20$ multilayer.

PRL 61 2472, PRL 72 408

Devices, Minority

Make use of minority spin carriers, so the states opposite to the field should be populate.

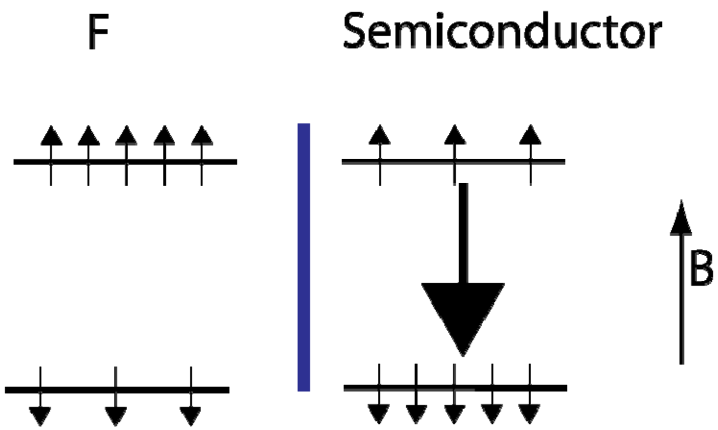
($Fe_{0.7}Cr_{0.3}$ Cu/Cr)



Devices, Negative g

Majority F and negative g

(InSb, InAs,…)



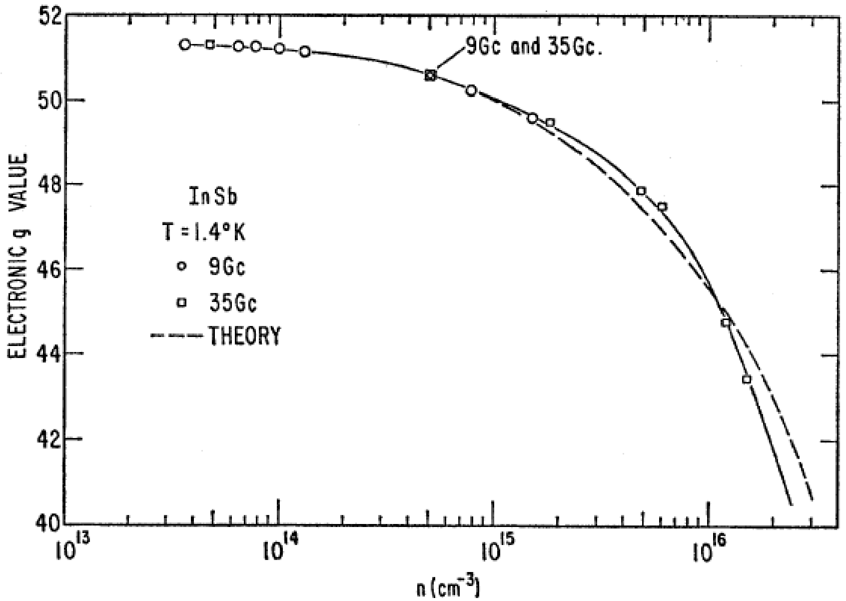


FIG. 1. Comparison of experimental g values for conduction electrons in InSb with theory. The electron concentrations were measured at 77°K. The small deviation between the two at high concentrations is unexplained.

Osipov, Viglin

Phys rev 169 312

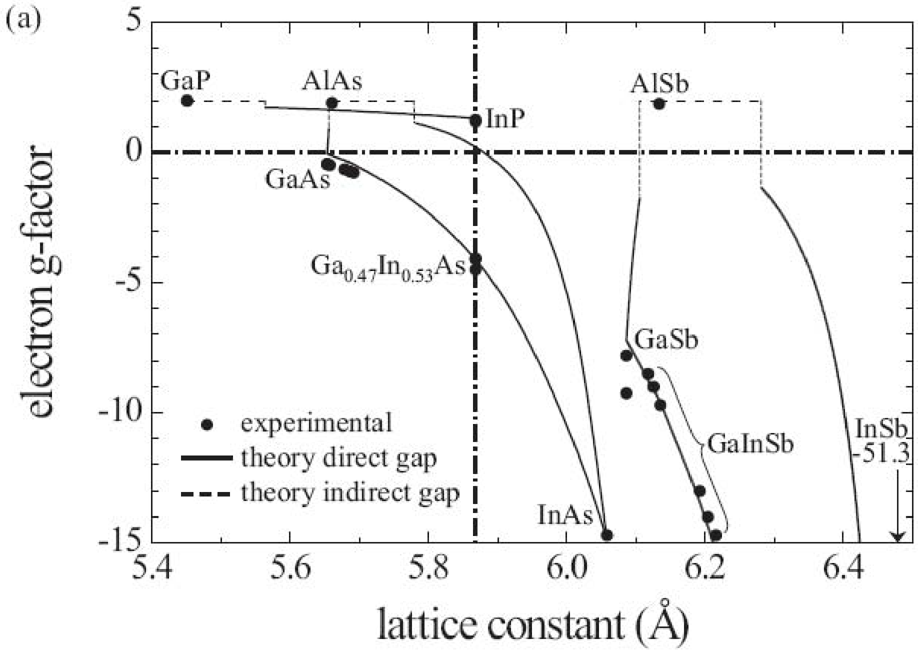
Negative g materials

Spin orbit splitting energy ~0.9 eV

$$\mu^* = \mu_0 \left(1 - \left[\frac{m}{m*}\right] \frac{\Delta}{3E_g + 2\Delta}\right)$$

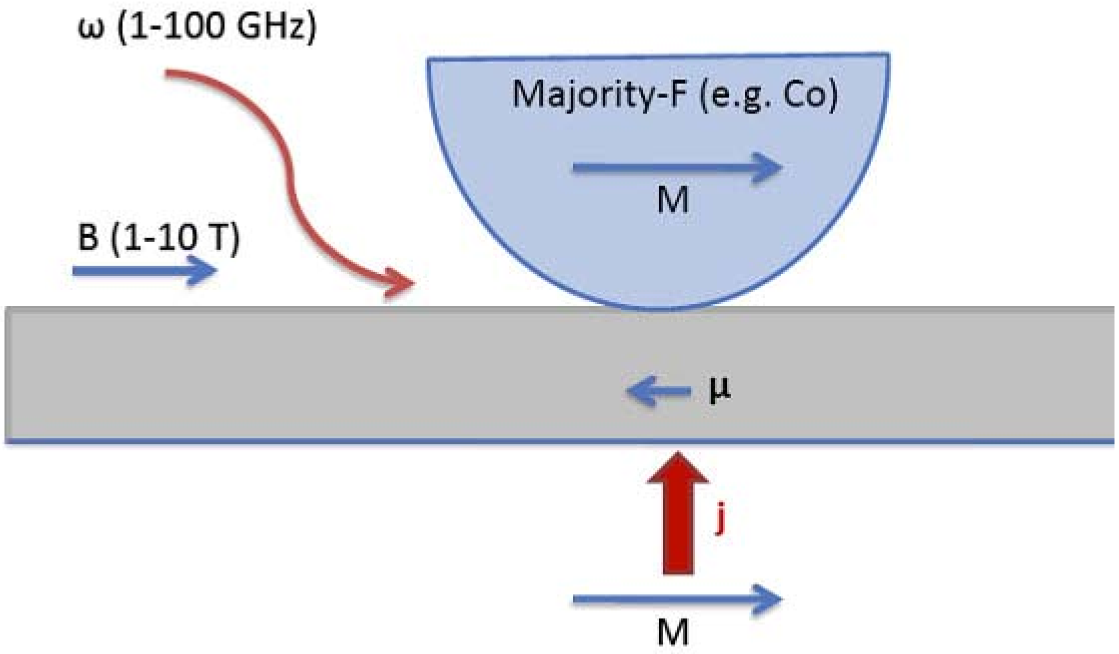
Bandgap
0.18 eV

Reduced mass ~m/70

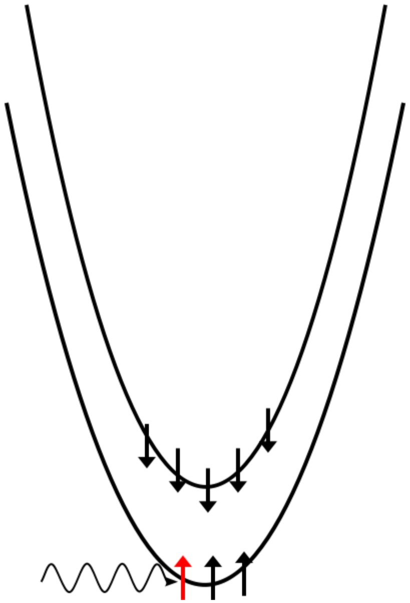


arXiv:quant-ph/0102056v2, phys rev 114, 90

Experimental Zeeman lasing



Expected spectroscop



$$\nu = \frac{g\mu_B m_s B}{h}$$

$$I(V) = \frac{V}{R} + \theta\left(1 - \frac{|\omega - 2\mu_B H_z|}{\omega}\frac{c}{v_f}\right) \cdot I_{ph}(V)$$

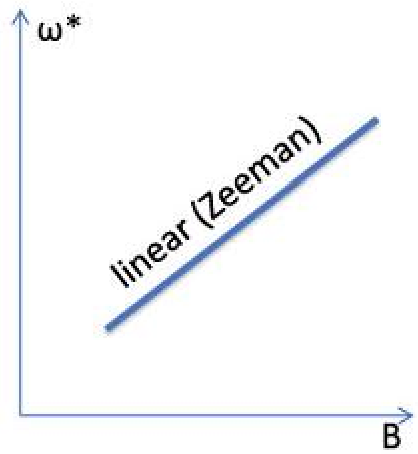
$$I_{ph}(V) = \frac{\Delta R}{R}(V - V^*)$$

Absorption

Emission

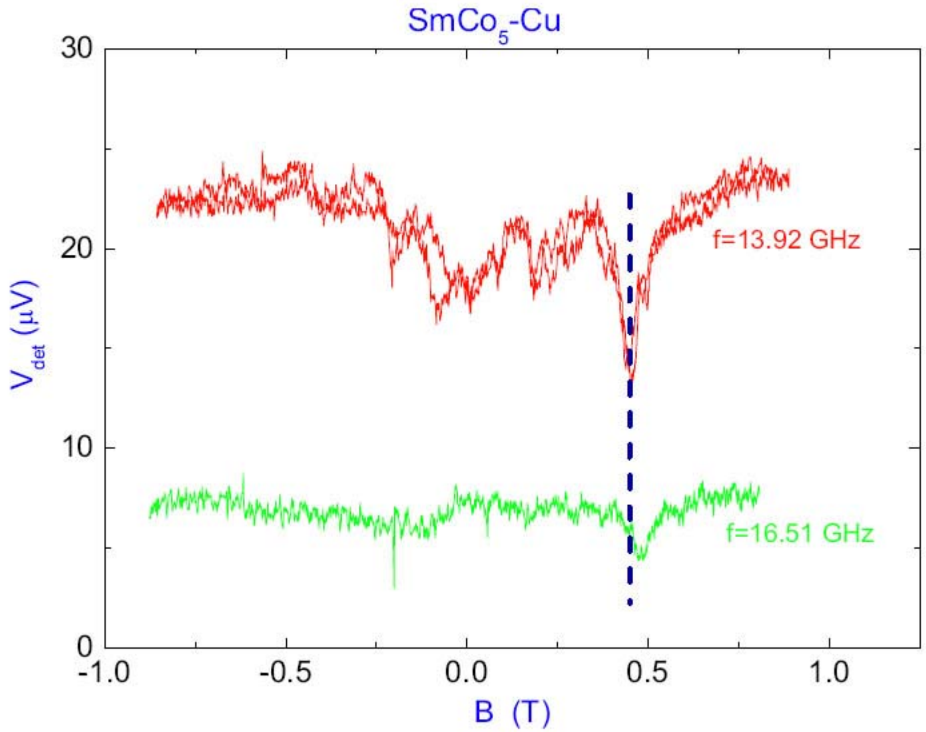
photon-induced PC resistance: $\Delta R/R \sim 10^{-4}$

j>j_crit



R. Shekter

First results (ILTPE)



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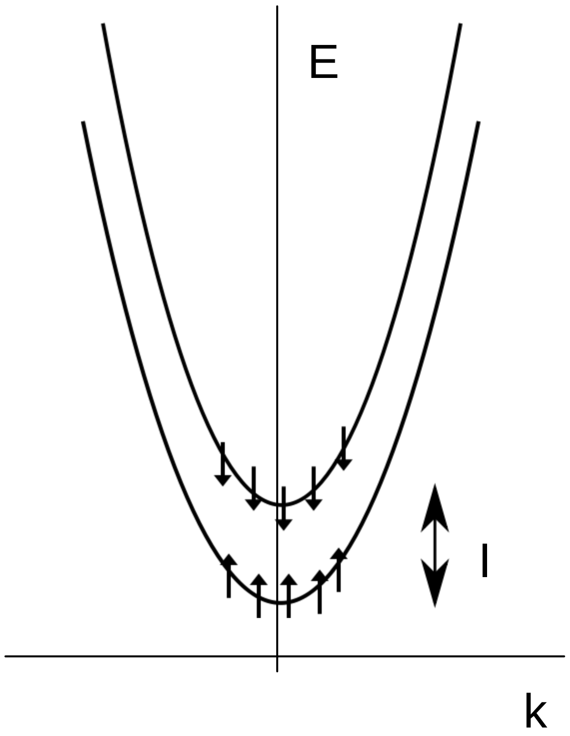
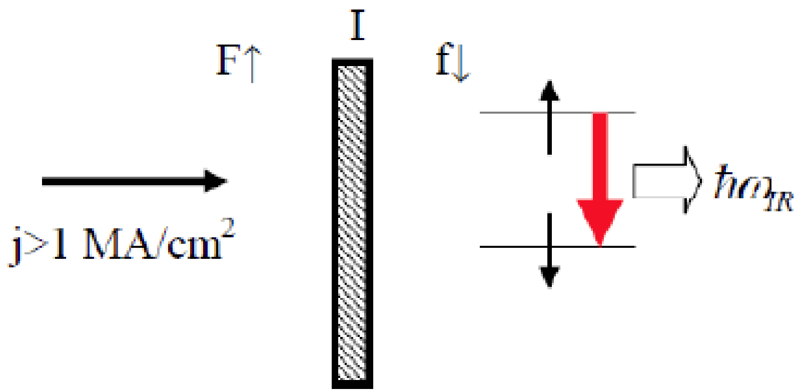
Exchange split transition





$$\begin{aligned} h\nu &= 2I \\ \nu &= 0.483 I [\mathrm{THz/meV}] \end{aligned}$$

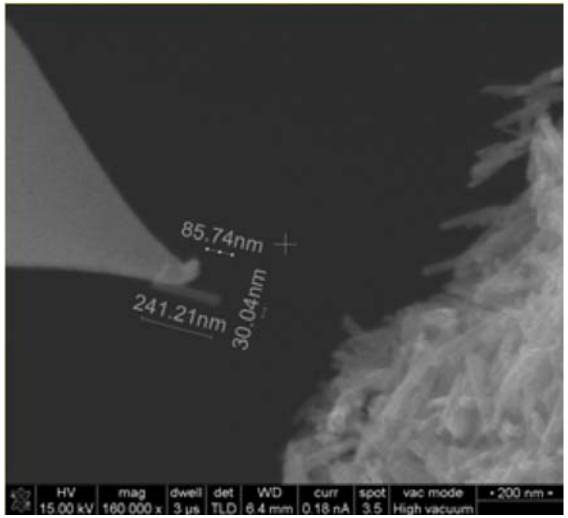
Kadigrobov, epl 67 948

Devices

- Majority F
- Minority f
- Pin/make easy switchable f layer

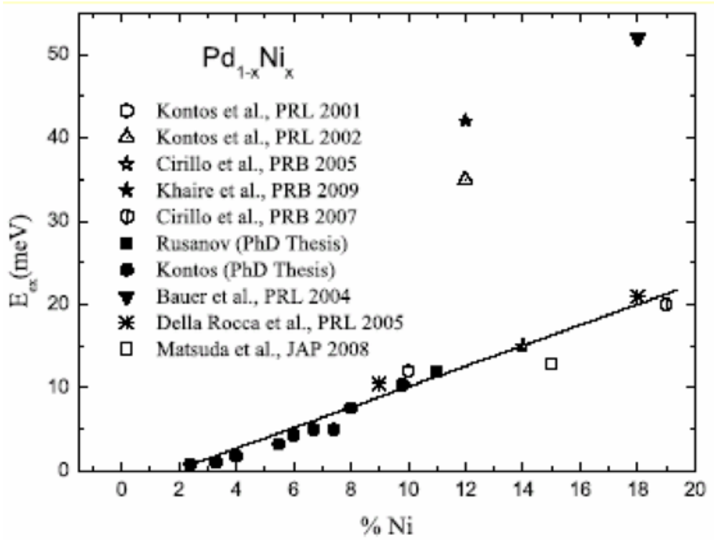
Materials

CrO_2 nanorods



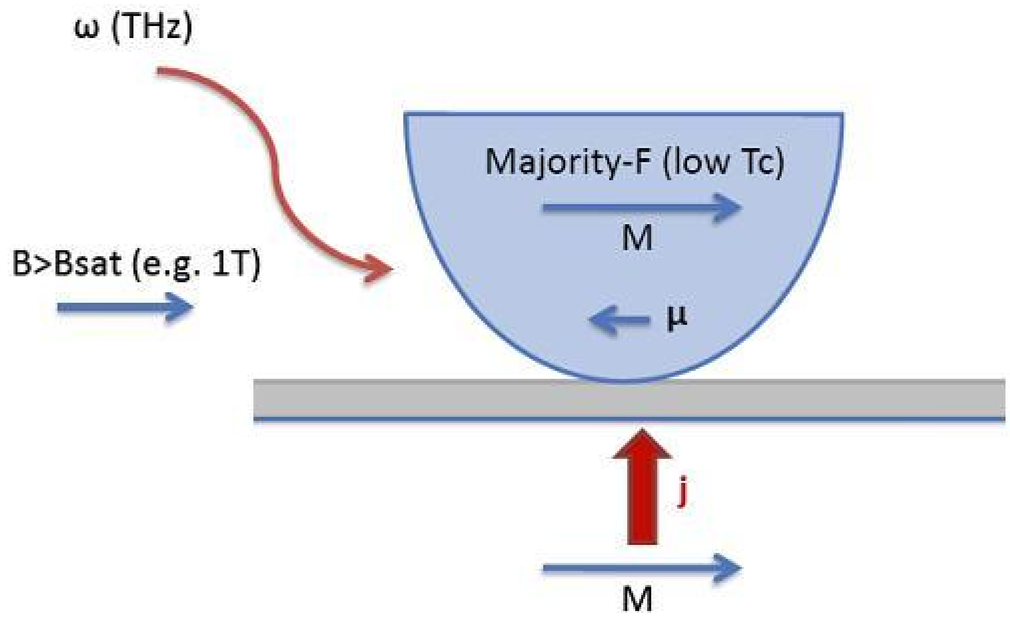
Tjerk Oosterkamp

$Pd_{1-x}Ni_x, Pd_{1-x}Fe_x, Cu_{1-x}Ni_x$



Review, Aarts et al

Experimental Exchange lasing



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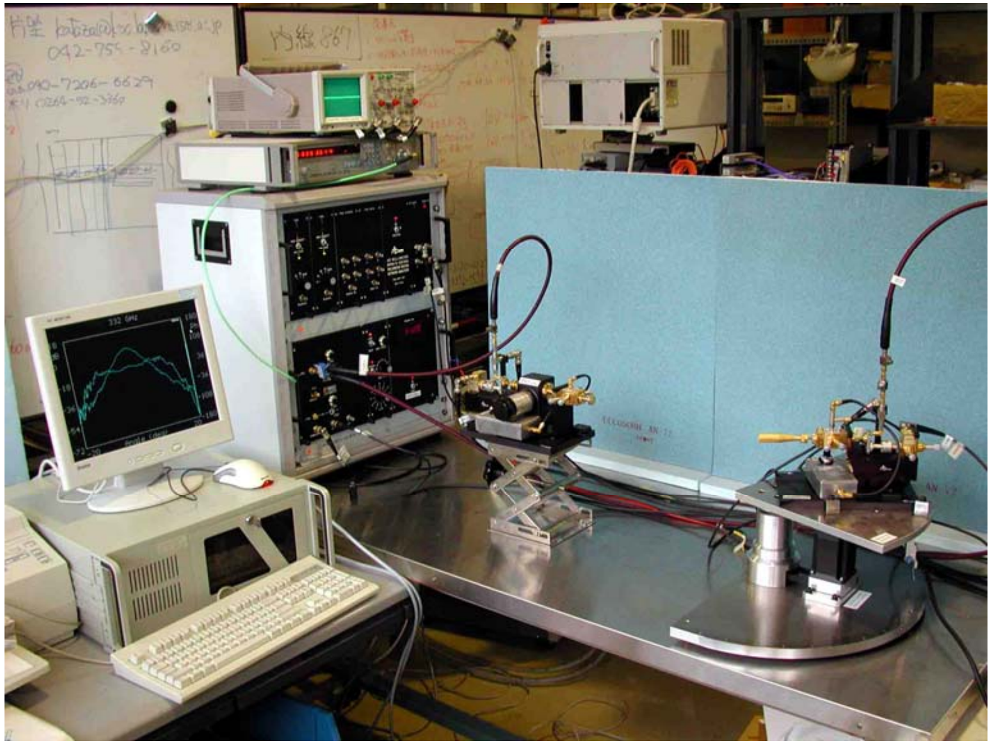
ABmm | 1-1000GHz

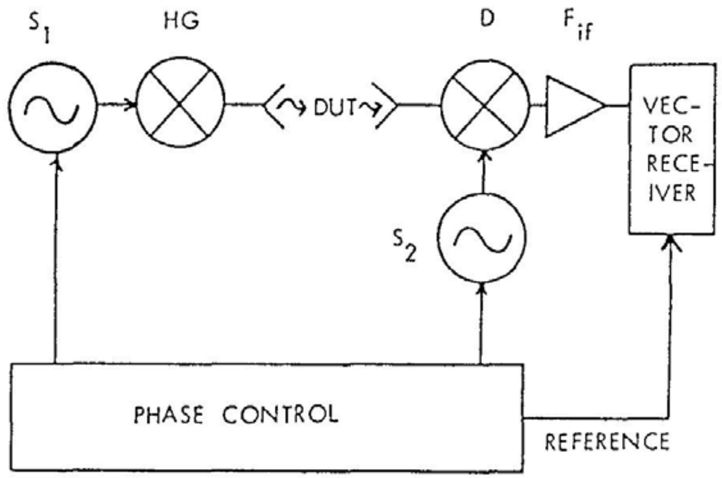
Harmonic generator as source (HG) and a harmonix mixer as detector (D)

HG is fed by centimeter source S1 and supplies the Nth harmonic

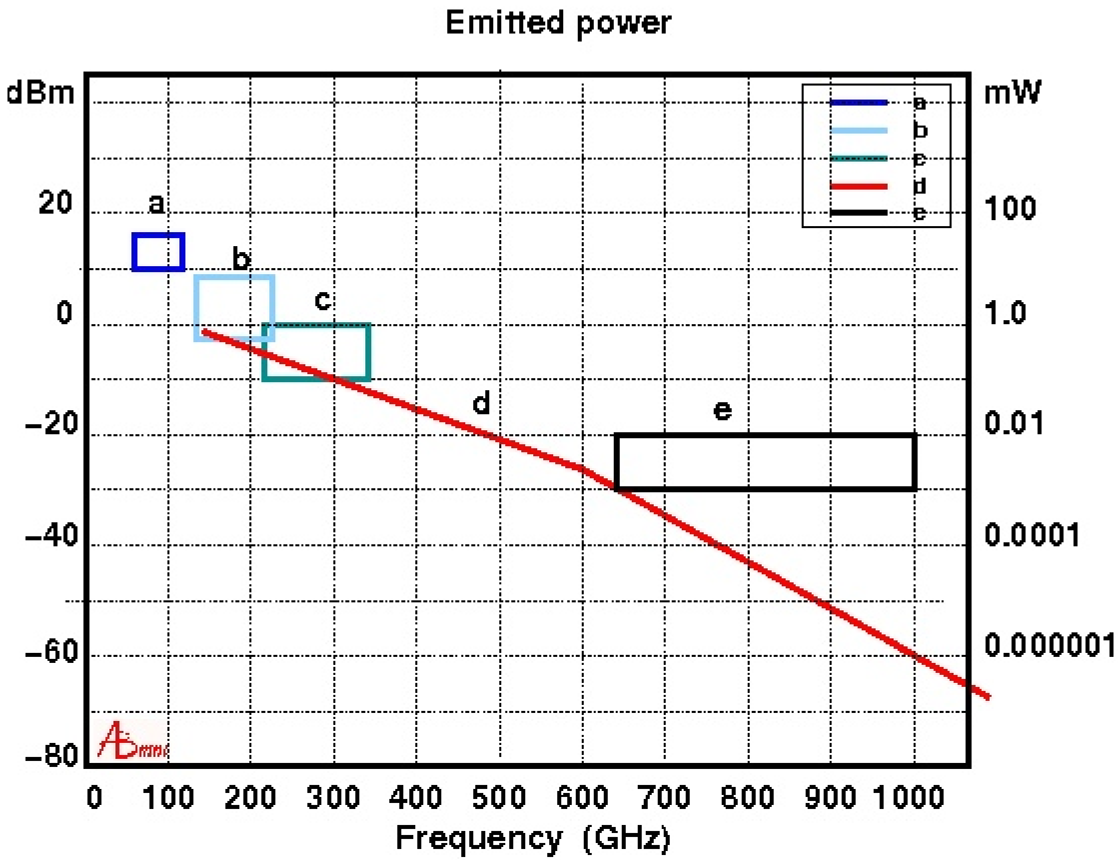
D is connected to the centimeter source S2 and supplies a beat frequency Fif

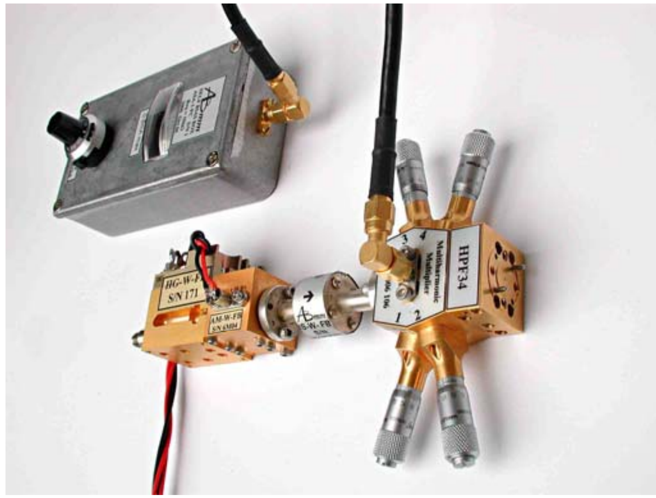
The receiver selects a given harmonic

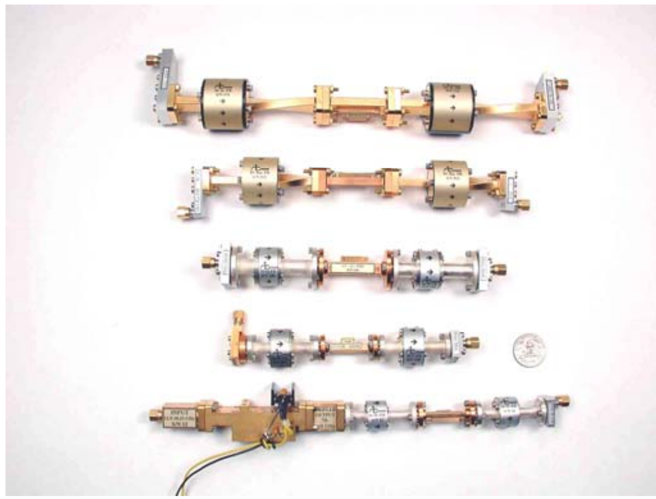




ABmm power


Emitted power
dBm
20
0
-20
-40
-60
-80
mW
100
1.0
0.01
0.0001
0.000001
a
b
c
d
e
0 100 200 300 400 500 600 700 800 900 1000
Frequency (GHz)





Fourier Transform Spectrometer

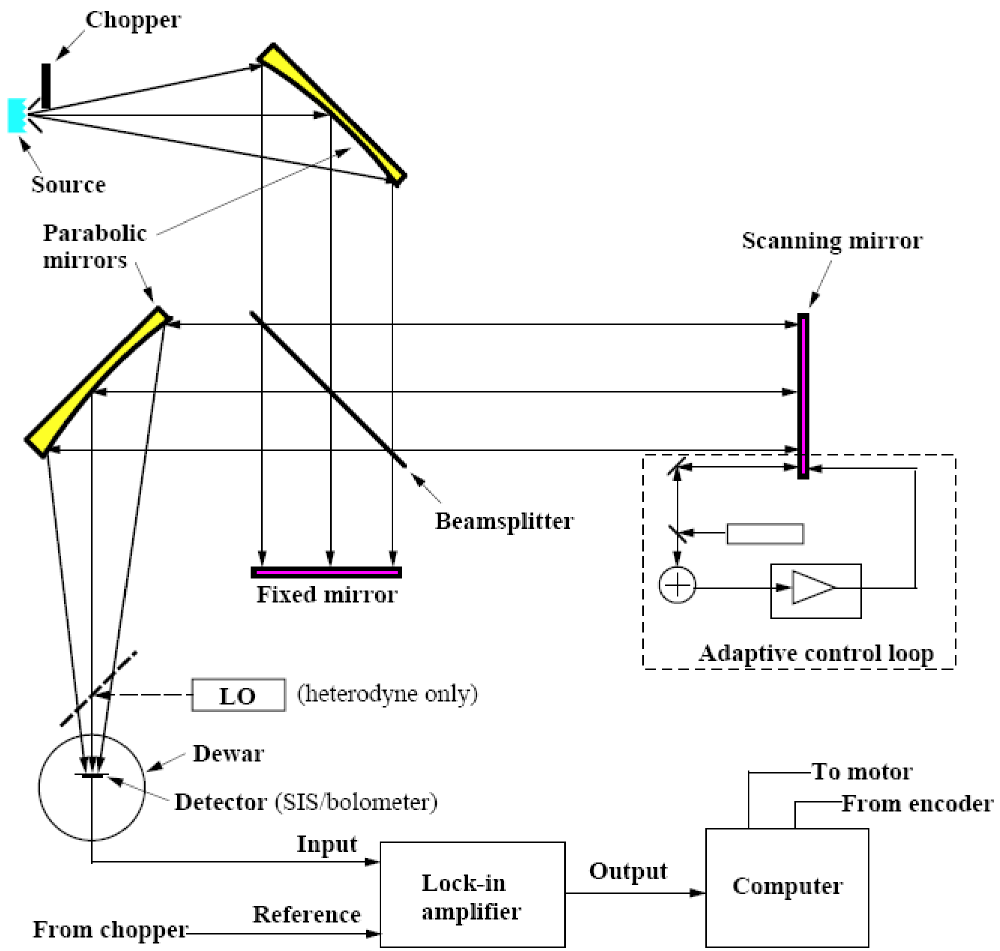
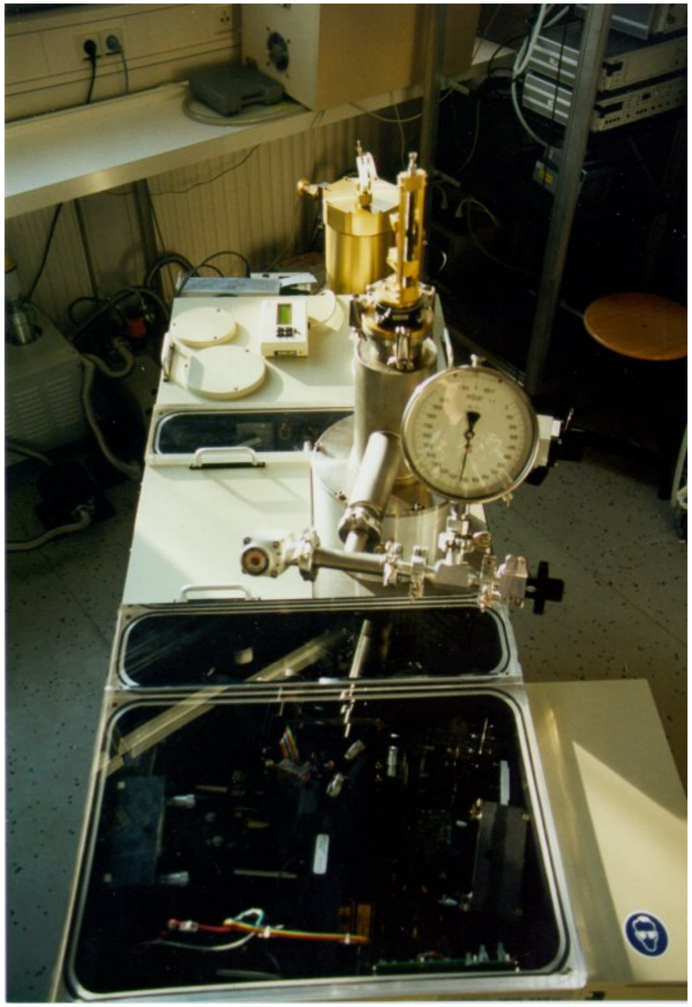


Fig. 1.— A block diagram of the FTS system.



Installed ~1THz – ~100 THz

Zmuidzinas, International Journal of Infrared and Millimeter Waves, Volume 20, Number 3 / March, 1999

Moveable mirror-frequency

$$I(\delta) = \int_{-\infty}^{\infty} I(\nu)\cos(2\pi\nu\delta)d\nu \qquad I(\nu) = \int_{-\infty}^{\infty} I(\delta)\cos(2\pi\nu\delta)d\delta$$

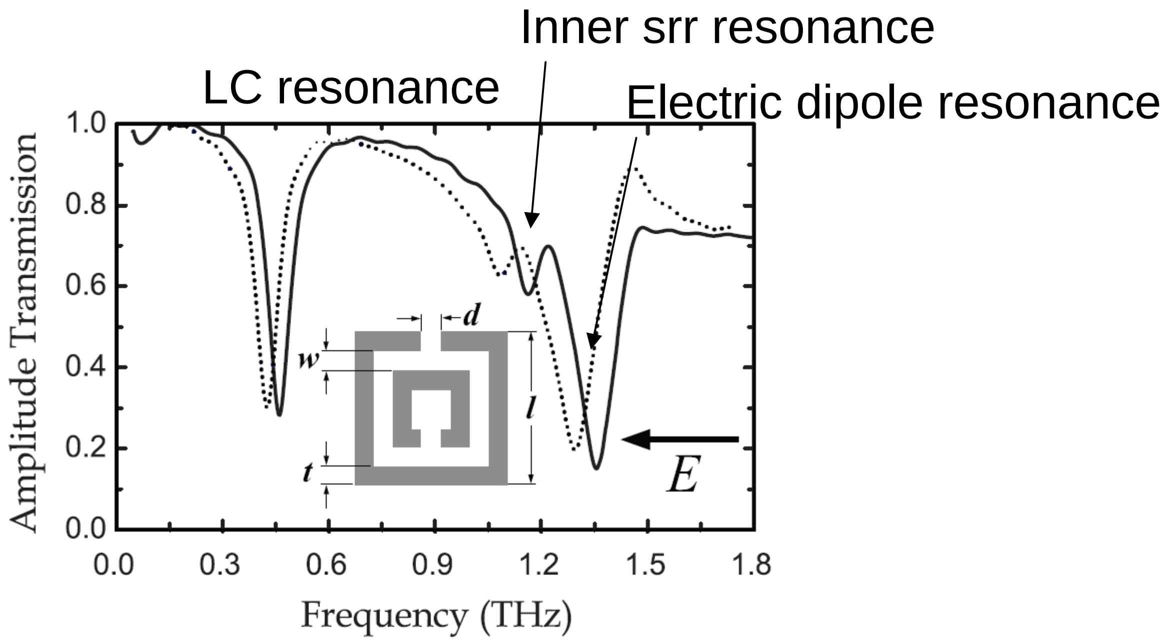


Fig. 1. Frequency-dependent amplitude transmission of a double SRR metamaterial without (solid curves) and with (dotted curves) a 16 μm thick photoresist overlayer.

$$d = 5\ \mu\text{m},\ w = 5\ \mu\text{m},\ t = 5\ \mu\text{m},\ l = 40\ \mu\text{m},$$

Optics express 16,1787

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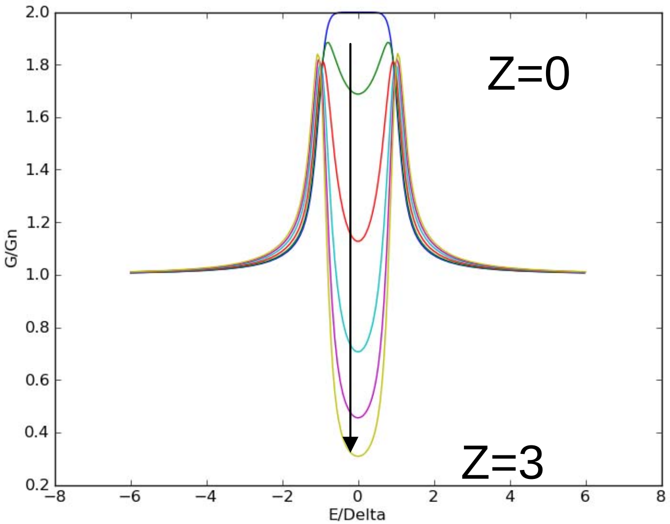
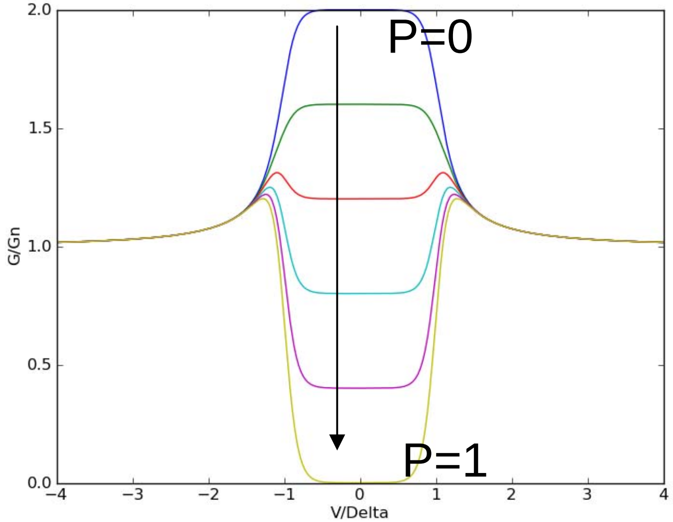
Current work
polarisation measurements

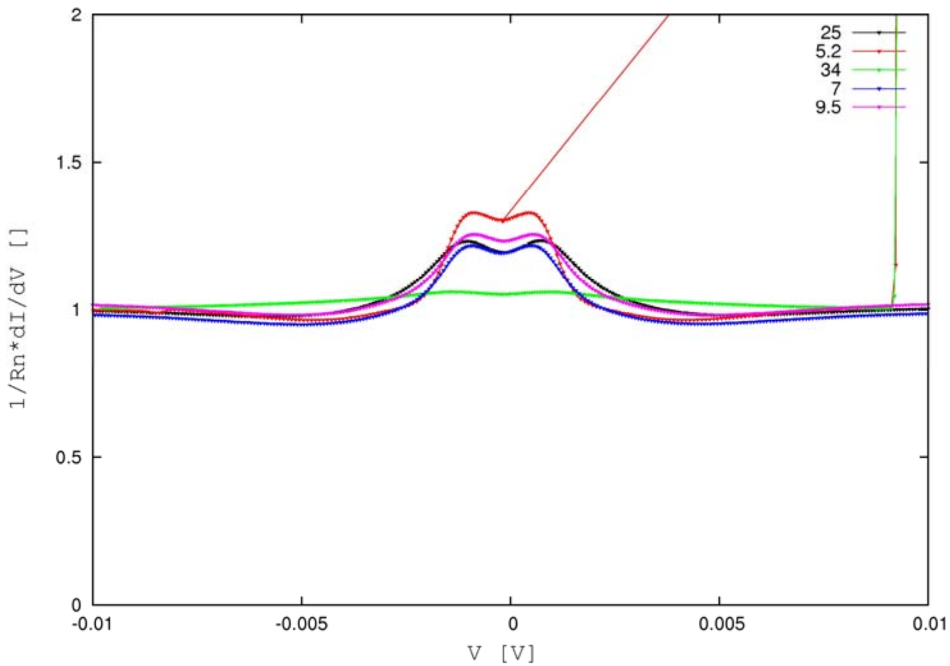
T = 1.5K, gap = 1.5meV



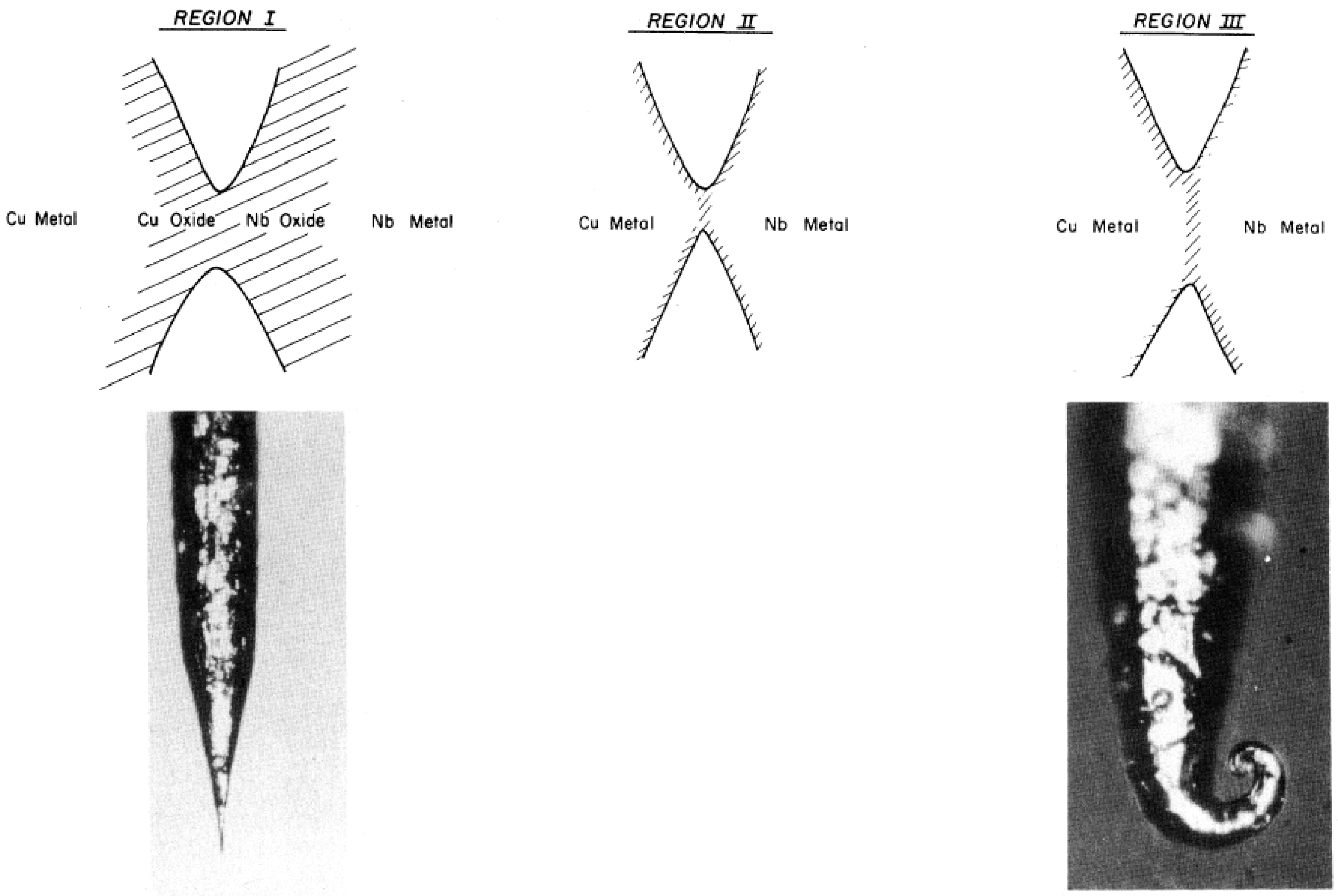


Z=0

Polarisation set up



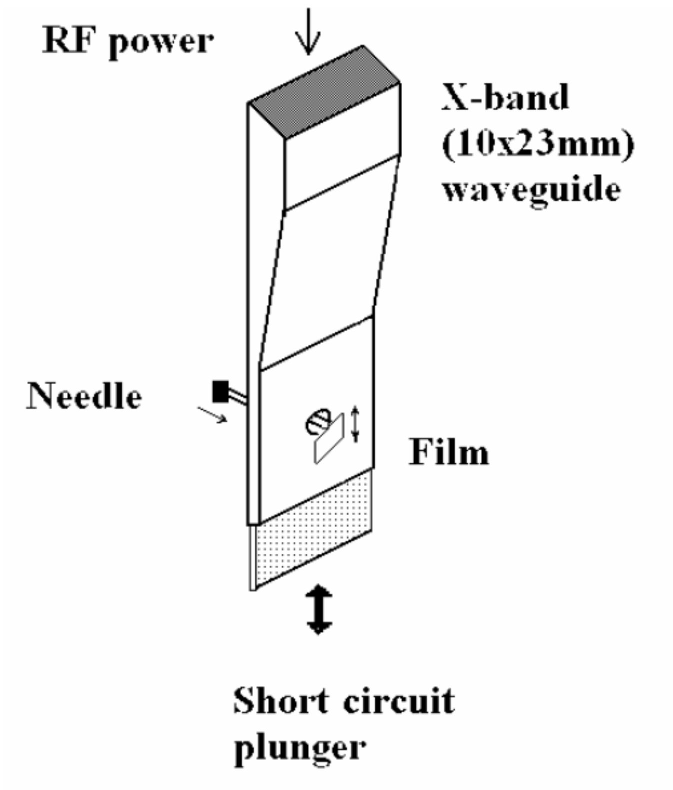
Learn how to measure PCS



PRB 27,112

Outlook / To Do

- Study possible materials using PCS
- Build setup to irradiate PC
- Measure PCS with radiation


RF power
X-band
(10x23mm)
waveguide
Needle
Film
Short circuit
plunger