



# Ferromagnetic-Metal Nanocomposite Films: A Possible Candidate for Left-Handed Materials

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# Outline



1. Nanocomposite films and LHMs
2. Ni-polyimide nanocomposite films
3. Ferromagnetic resonance study
4. Summary & Future works

# left-handed materials



Left-Handed Materials (LHMs) :

Material with both permittivity ( $\epsilon$ ) and permeability ( $\mu$ ) negative

Extraordinary electromagnetic response (Veselago, 1964)

*e.g., inverse Doppler shift, negative index of refraction*

*V.G.Veselago, Usp. Fiz. Nauk 92, 517 (1964).*

## Negative $\mu$ ?

### 1. Metamaterials:

Array of split-ring resonantors

*R.A.Shelby, D.R.Smith, and S.Schultz, Science 292, 77 (2001).*

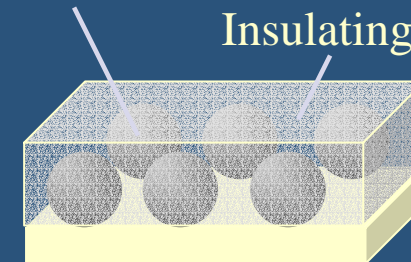
### 2. Ferromagnetic-metal (FM-M) nanocomposite films

*Using ferromagnetic resonance(FMR)*

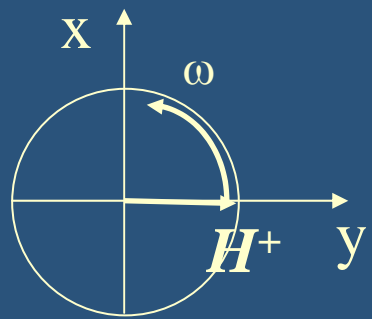
*S.T.Chui and L.Hu, Phys. Rev. B 65, 144407 (2002).*

Ferromagnetic-metal nanoparticle

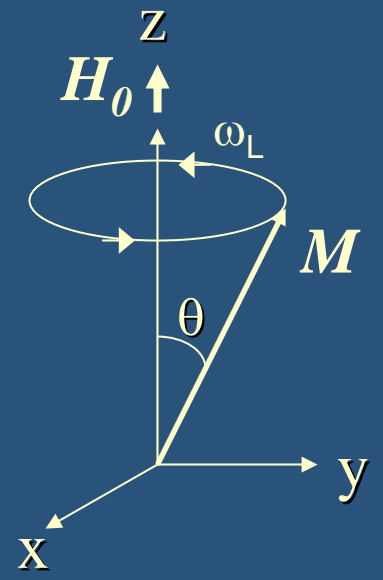
Insulating matrices



# ferromagnetic resonance

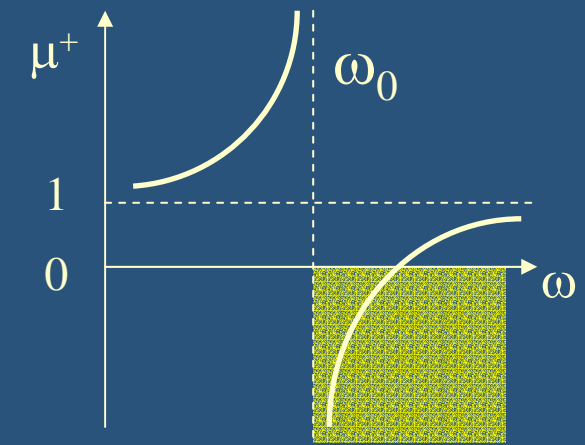


Positive circularly polarised microwave ( $\omega$ ):



Magnetic moment under applied field  $H_0$ :  
Precession with Larmor frequency ( $\omega_0$ )

$\omega = \omega_0$ :  
*ferromagnetic resonance (FMR)*



Negative  $\mu^+$

The idea....

# FM-M nanocomposite for LHMs



## FM-M nanocomposite films

$$\epsilon < 0$$

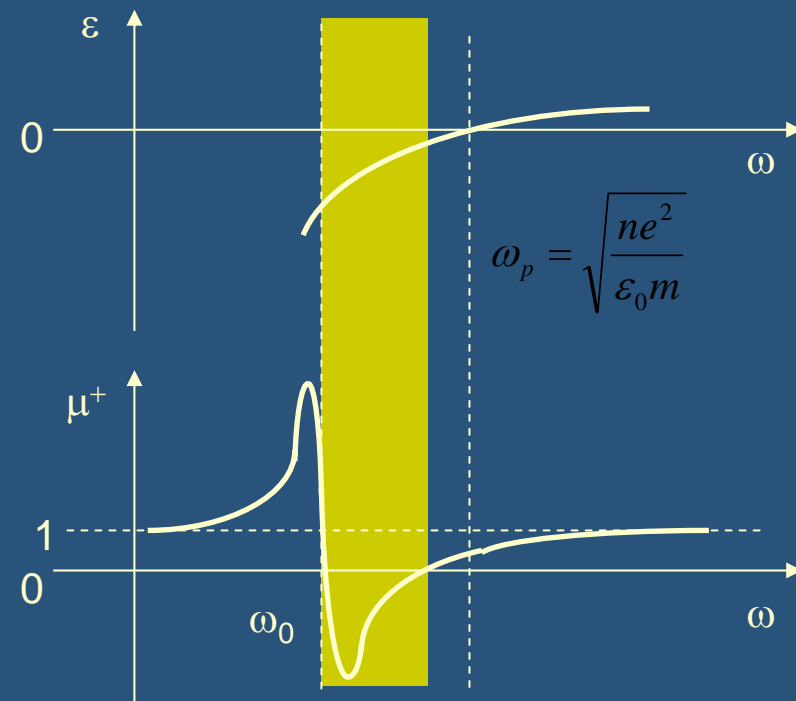
@ below plasma frequency  
of metal ( $\omega_p$ )

$$\mu^+ < 0$$

@ vicinity of FMR frequency ( $\omega_0$ )

low eddy current loss

A possible candidate  
for LHMs **at vicinity of a FMR frequency**  
(microwave region)



# this project



## Mission:

Realization of LHMs using FM-M nanocomposite

## Present study:

### 1. Preparation of FM-M nanocomposite for LHMs

A. Fe-SiO<sub>2</sub> nanocomposite films

By co-sputtering method

B. Ni-Polyimide nanocomposite films

By chemically implantation

### 2. FMR studies of nanocomposite films