Ultra-Thin Magnetic Multilayer Films for Monolithic Microwave Devices

Bijoy K. Kuanr[1], Alka V. Kuanr[2], R. E. Camley[1] & Z. Celinski[1]
[1]Physics Department, University of Colorado, Colorado Springs, CO, USA.
[2]Shaheed Rajguru College of Applied Science for Women, Jhilmil Colony, Delhi, India.

Microwave filters using ferromagnetic metals are now being established as a valuable option compared to YIG based filters due to their higher frequency response[1]. In this work, we present the first ever application of interlayer exchange coupling energy to boost the operating frequency for co-planer waveguides based microwave filters. High quality epitaxial Fe/Si(t)/Fe multilayer films were deposited on GaAs substrates, which are inter-layer exchange coupled through non-magnetic Si of different thicknesses. Using optical lithography and then ion-etching, we fabricated the co-planer waveguides filters (Fig.1). These filters were investigated by using a Network Analyzer for their stop-band performance. Fig.2 depicts transmission characteristic of Fe and Fe/Si/Fe films based filters at 60 Oe. The resonance frequency (f_{res}) for Fe film occurred at 10.6 GHz, whereas for Fe/Si/Fe sample with Si thickness of 1 nm, f_{res} was pushed to 21.2 GHz for the same magnetic field. However, for thinner Si thicknesses in Fe/Si/Fe trilayers f_{res} was further pushed upward. For Fe/Si/Fe samples with Si thicknesses of 0.7 nm and 0.8 nm, f_{res} was recorded at 27.25 GHz and 27.73 GHz, respectively. Using the MOKE experimental values[2] of $4\pi M_S$=21.5 kOe and H_{an}=600 Oe, it was found that 60 Oe field corresponds to a theoretical f_{res} =10.7 GHz for a single layer Fe film. The huge enhancement of f_{res} up to 27.73 GHz for the Fe/Si(0.8 nm)/Fe exchange-coupled film may be attributed to a large interlayer exchange coupling energy[2] ($J_{eff} = J_1 - 2J_2$).

Table I depicts the correspondence of f_{res} to different interlayer exchange coupling energies. Although bilinear part (J_1) of interlayer exchange coupling is the maximum for 0.7 nm Si sample, f_{res} is not maximum for this trilayer. The biquadratic part (J_2) played a great role in determining the effective exchange coupling (J_{eff}) and hence f_{res}. The J_{eff} is the maximum[2] for Si thickness of 0.8 nm and hence f_{res} is maximum for this sample. A detailed theoretical calculation will be reported. We concluded that the main resonance mode shifts to much higher frequency due to the antiparallel/spin-flop alignment of magnetizations of the two Fe layers. These filters also show a reasonably good value of quality factor (Q) at microwave frequencies. The 3-dB frequency linewidth for the exchange coupled Fe/Si/Fe samples have linewidth (Δf) of 350 MHz, 750 MHz and 300 MHz for Si thickness 0.7 nm, 0.8 nm and 1 nm in the trilayer of Fe/Si/Fe.

TABLE I : Stop-band resonance frequency to interlayer exchange coupling energies [from Ref. 2].

Si(t)(nm)	J_1 (Bilinear) (erg/cm^2)	J_2 (Biquadratic) (erg/cm^2)	$J_{eff}=J_1-2J_2$ (Effective) (erg/cm^2)	f_{res} (GHz)
0.7	-6.5	-1.1	-4.3	27.25
0.8	-5.66	-0.44	-4.78	27.73
1.0	-2.61	-0.2	-2.21	21.2

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[2] M. Buchmeier, B. K. Kuanr, R. R. Gareev, D. E. Buergler & P. Gruenberg, Phys. Rev. B 67, 8605 (2003).

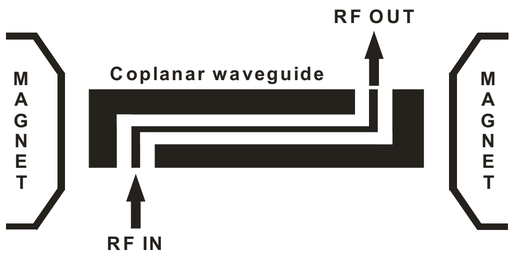
RF OUT
Coplanar waveguide
MAGNET
MAGNET
RF IN

Fig. 1

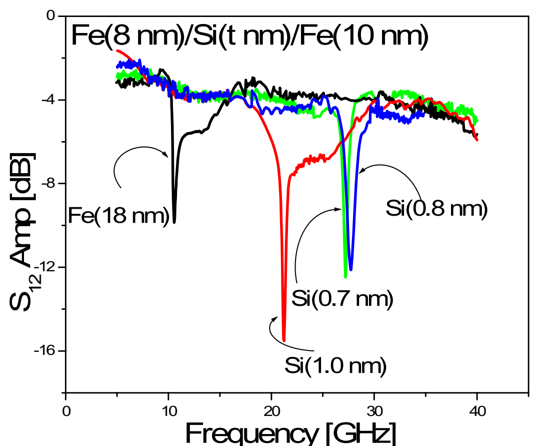
Fe(8 nm)/Si(t nm)/Fe(10 nm)
Fe(18 nm)
Si(0.8 nm)
Si(0.7 nm)
Si(1.0 nm)
S12 Amp [dB]
Frequency [GHz]
0
-4
-8
-12
-16
0
10
20
30
40

Fig. 2