Magnetic properties and relaxation of the magnon populations in the super lattice [Fe/GaAs]

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Abstract: In the present work we study the properties of elementary excitations in a magnetic super lattice [Fe/GaAs] which is described in framework of the ferromagnetic Heisenberg system where the exchange and the dipolar interactions, the magneto-crystalline and surface anisotropies are all taking into account. The corresponding Hamiltonian is treated by the Green's function method. The analytical expressions of the excitation spectrum and the magnetization per spin are obtained when the exchange is present alone. A good adjustment of calculated magnetization with the experimental results is obtained for various magnetic layer thickness (t_{Fe}). The deduced exchange integrals are in agreement with previous studies. The combined effect of dipolar interactions and surface anisotropy is studied numerically.

I. Introduction :

The studies of ultrathin magnetic films on semiconductor substrates making use of both the electronic charge and the spin of conduction electrons are highly motivated by the possibility to exploit novel functionalities in advanced devices [1-3]. The largest body of work for magnetic 3d TM (as Fe) on semiconductors is for the zincblende compounds (as GaAs). This is because the nearly factor of two relationship between the lattice constants of the metals and the semiconductors and also because of their ready availability either as bulk substrate material or as epitaxial semiconductor films upon readily available substrates. The small band gap (1.4 eV) III-V compound GaAs is indeed mismatched ≈ 1.3 $^0/_0$ smaller than bcc Fe. It was also found that Fe would grow epitaxially on (100) [4], (001) [5] and on (110) [6] GaAs. Although a cubic bcc Fe is grown upon a closely matched cubic substrate GaAs the system Fe/GaAs should however exhibit evidence of a uniaxial distortion in its magnetic anisotropy [7]. It presents an angular dependence of anisotropy energy and a reverse in the role of easy axis to hard axis can be obtained when the Fe film thickness t_{Fe} decreases [8-12]. For $t_{Fe} < 10\,ML$ (as in present work), an uniaxial anisotropy with the easy axis of the in-plane magnetization dominates [4]. Furthermore, several theoretical as well as experimental works on the [3d-TM/NM] systems, where NM is non magnetic layer, showed that quasi two-dimensional (2D) systems have some magnetic properties different from that in three-dimensional (3D) case. In particular the main role of the anisotropy in the magnetic state stability, the existence of a dimensionality crossover where the magnetic interactions pass from 3D behavior (magnetization varies in $T^{3/2}$) to 2D behavior (magnetization varies in $T\ln T$) with increasing temperatures are revealed [13-19].

In this work we present a theoretical study in which we calculate excitation spectrum $E(k)$ and magnetization per spin $m_z(T) = \langle S_z \rangle / S$ for the system under consideration [Fe/GaAs] with various magnetic thicknesses t_{Fe}. A comparison of our calculated magnetization with measured results is made and a good adjustment of these results is obtained. The deduced exchange integral values J are in a satisfactory agreement with values previously obtained [20-24]. A numerical study of the surface anisotropy and dipolar interaction combined effect on the magnetization per spin is also obtained.

II. The spin hamiltonian:

To study the properties of the super lattice [Fe/GaAs] we consider that it made up of an iron layer of N magnetically coupled atomic planes deposited on a semiconductor layer GaAs. The easy axis of magnetization is parallel to the ferromagnetic plane (OXZ). The Heisenberg Hamiltonian of such a system can be expressed as follows:

$$\begin{aligned}\mathscr{H} = &- \sum_{ij} J_{ij}^{//}(s_i^x s_j^x + s_i^y s_j^y + \Delta\, s_i^z s_j^z) - \sum_{ii'} J_{ii'}^{\perp}(\vec{s}_i \vec{s}_{i'}) \\ &+ \frac{1}{2}\sum_{ij} \frac{(g\mu_B)^2}{r_{ij}^3}\left(\vec{s}_i\vec{s}_j - 3\frac{(\vec{s}_i\vec{r}_{ij})(\vec{s}_j\vec{r}_{ij})}{r_{ij}^3}\right) \\ &+ \frac{1}{2}\sum_{ii'} \frac{(g\mu_B)^2}{r_{ii'}^3}\left(\vec{s}_i\vec{s}_{i'} - 3\frac{(\vec{s}_i\vec{r}_{ii'})(\vec{s}_{i'}\vec{r}_{ii'})}{r_{ii'}^3}\right) - \alpha \sum_i \left(s_i^y\right)^2\end{aligned} \tag{1}$$

The exchange integrals between the first neighbors in the same plane are $J_{ij}^{//}$, while $J_{ij}^{\perp}$ correspond to the exchange between two successive planes first neighbors. The surface and the magneto-crystalline anisotropies are represented respectively by α and Δ.

Using the usual Fourier and Holstein-Primakoff transformations [25], (1) becomes:

$$\mathcal{H}=\sum_{l,m}^{N}\sum_{k}\left\{A_{lm}(k)a_{k,l}^{+}a_{k,m}+\frac{1}{2}B_{lm}(k)\left(a_{k,l}^{+}a_{-k,m}^{+}+a_{k,l}a_{-k,m}\right)\right\} \tag{2}$$

$k=(k_x,k_z)$ and A_{lm} and B_{lm} are obtained for the atomic plans l and m ($1\le l\le N$ and $1\le m\le N$) by:

$$\begin{aligned}A_{lm}(k)=S\Bigg\{&\sum_{\delta_{//}}\left[2J_{\delta_{//}}^{//}(\Delta-\cos(k\,\delta_{//}))+D_{\delta_{//}}\left(\left(1-\tfrac{3}{2}\left(\frac{r_{\delta_{//}}^{x}}{r_{\delta_{//}}}\right)^{2}\right)\cos(k\,\delta_{//})-\left(1-3\left(\frac{r_{\delta_{//}}^{x}}{r_{\delta_{//}}}\right)^{2}\right)\right)\right]\\&+\sum_{\delta_{\perp}}\left(2J_{\delta_{\perp}}^{\perp}+D_{\delta_{\perp}}\left(3\left(\frac{r_{\delta_{\perp}}^{x}}{r_{\delta_{\perp}}}\right)^{2}-1\right)\right)\left(2-\delta_{l,1}-\delta_{l,N}\right)-\alpha(\delta_{l,1}+\delta_{l,N})\Bigg\}\delta_{l,m}\\&-S\left[2\sum_{\delta_{\perp}}J_{\delta_{\perp}}^{\perp}\cos(k\,\delta_{\perp})-D_{\delta_{\perp}}\left(1-\tfrac{3}{2}\left(\frac{r_{\delta_{\perp}}^{x}}{r_{\delta_{\perp}}}\right)^{2}\right)\cos(k\,\delta_{\perp})\right]\left(\delta_{l,m-1}+\delta_{l,m+1}\right)\end{aligned} \tag{3}$$

$$\begin{aligned}B_{lm}(k)=S&\left(-\tfrac{3}{2}\sum_{\delta_{//}}D_{\delta_{//}}\left(\frac{r_{\delta_{//}}^{x}}{r_{\delta_{//}}}\right)^{2}\cos(k\,\delta_{//})+\alpha(\delta_{l,1}+\delta_{l,N})\right)\delta_{l,m}\\&-\tfrac{3}{2}S\sum_{\delta_{\perp}}D_{\delta_{\perp}}\left(\frac{r_{\delta_{\perp}}^{x}}{r_{\delta_{\perp}}}\right)^{2}\cos(k\,\delta_{\perp})\left(\delta_{l,m-1}+\delta_{l,m+1}\right)\end{aligned} \tag{4}$$

$r_{\delta_{//}}=(r_{\delta_{//}}^{x},r_{\delta_{//}}^{y},r_{\delta_{//}}^{z})$ are distances between first neighbors in the same plane. While $r_{\gamma_{\perp}}=(r_{\gamma_{\perp}}^{x},r_{\gamma_{\perp}}^{y},r_{\gamma_{\perp}}^{z})$ are distances between first neighbors belonging to two different planes and $D=\dfrac{g^{2}\mu_{B}^{2}}{(r)^{3}}$ is the dipolar interaction constant.

The diagonalization of the Hamiltonian expression (2) is obtained by using the Green's function G technique defined by: $G_{l,m}=\ll a_{k,l},a_{k,m}^{+}\gg$ and $G'_{l,m}=\ll a_{-k,m}^{+},a_{k,m}^{+}\gg$. The G equations of movement lead to a 2N coupled equation system represented in the matrix form such as:

$$\begin{pmatrix}A-E & B\\ -B & -B-E\end{pmatrix}\begin{pmatrix}G & 0\\ G' & 0\end{pmatrix}=-\frac{1}{2\pi}\begin{pmatrix}1 & 0\\ 0 & 0\end{pmatrix} \tag{5}$$

A and B are $N\times N$ matrices with elements given by the equations (3) and (4) above.

III -The Hamiltonian of the exchange alone.

3.1. Excitation spectrum

3.1.1. Calculated results and discussion

It is now well established that in 3d MT like iron, the effect of the magnetic exchange is largely more important than that of the anisotropy and the dipolar interactions. Thus, we treat first of all the effect of the exchange alone such as $D=\alpha=0$. The anisotropy and dipolar terms will be analyzed later on. So, the hamiltonian (2) is reduced to:

$$\mathcal{H}=\sum_{lm}\sum_{k}A_{lm}(k)\,a_{k,l}^{+}\,a_{k,m} \tag{6}$$

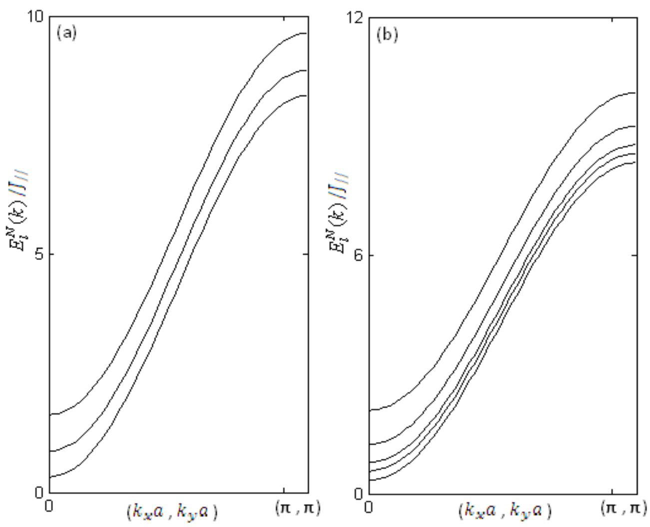
The excitation spectrum $E_l^N(k)$ for a plane l is obtained in the same way that for the previously studied analogous magnetic super lattices [20-24] by solving the secular equation:

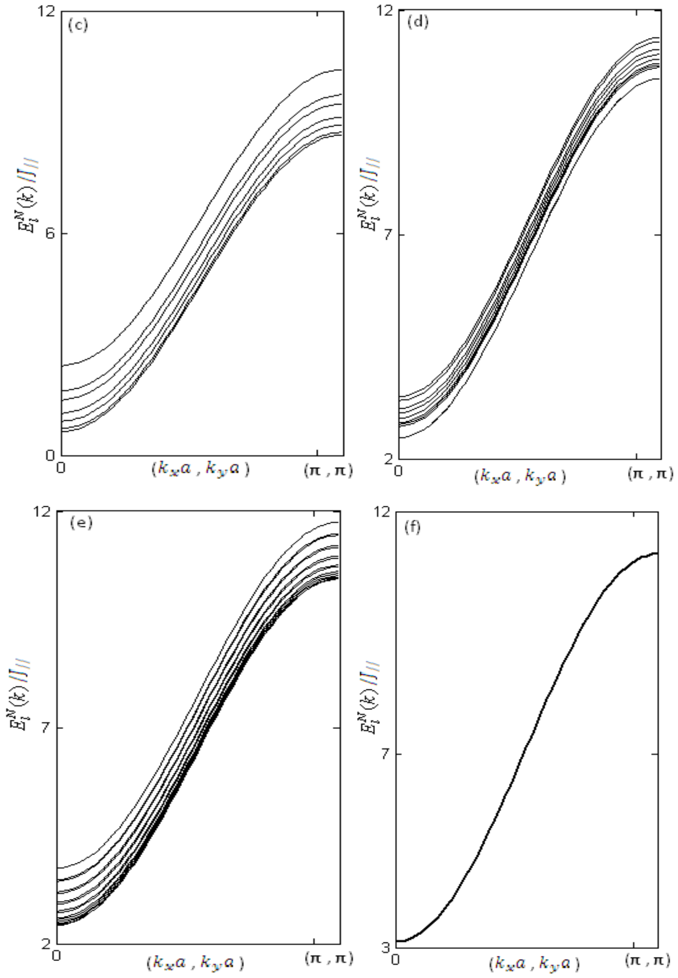
$$\mathrm{Det}\left[A-E\,I\right]=0 \tag{7}$$

Giving: $$E_l^N(k)=A(k)+\varepsilon_l^N W(k) \tag{8}$$

$$A(k)=A_{11}(k)\quad;\quad W(k)=-A_{12}(k)$$

We note that for low numbers N of planes, the series of values ε_l^N specifying solutions $E_l^N(k)$ contains N distinct values (see figures 1 a ; b and c) agreeing with results of former studies [20-24; 26]. The break of symmetry at the interfaces acquires an impact which is increasingly important that the number N is weak. What would be probably at the origin of the complete distinction of the energy levels of magnons. Whereas, when N increases the number of modes differs from magnetic plane number N (figures 1 d ; e and f). For the bulk samples N>>1, there is no more than only one completely degenerated mode of created magnons (figure 1f). Indeed, when the number N increases the volume of the sample becomes more and more dominating and at the limit N>>1 the magnon states are completely degenerated.





Figures 1: Excitation spectra calculated for the super lattices [Fe (t_{Fe})/GaAs] with:

(a) $t_{Fe} = 6\,\mathring{A}\,(N=3)$; **(b)** $t_{Fe} = 10\,\mathring{A}\,(N=5)$; **(c)** $t_{Fe} = 14\,\mathring{A}\,(N=7)$; **(d)** $t_{Fe} = 20\,\mathring{A}\,(N=10)$ and **(e)** $t_{Fe} = 30\,\mathring{A}\,(N=15)$ **(f)** a thick magnetic layer N(Fe)>>1.

3.1.2. Analyze of the opening of the created magnon state gap

As shown on the figure 1, the spectrum $E_l^N(k)$ presents an energy threshold E_{Thres}^N corresponding to the lower energy level. It's defined as a gap energy E_g and it depends on the anisotropy. It is responsible for the existence of a long rang magnetic order and also of the creation of magnons. Moreover, a phase diagram $E_g\ (\Delta,\ J_\perp/J_\parallel)$ is obtained by solving graphically the equation: $E_g = E(k) = 0$ in the vicinity of $k_{//} = (0,0)$ with:

$$E_g = A_{11}\ (k) - W = 8J_\parallel\ S(\Delta\ -1) - 2J_\perp S \tag{9}$$

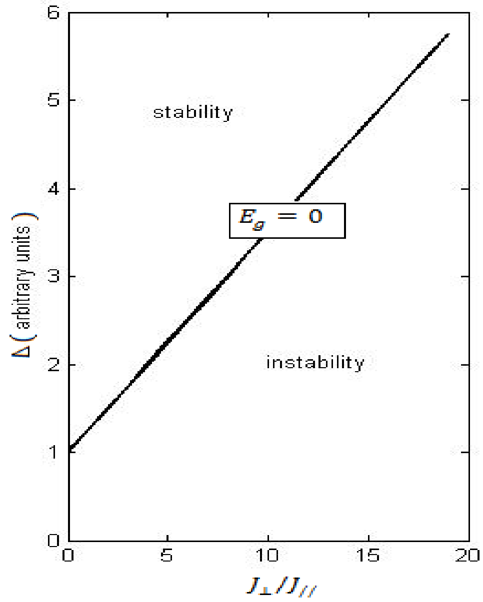


Figure 2: Phase diagram representing the variation of magneto-crystalline anisotropy Δ according to the exchange ratio $J_\perp/J_\parallel$ corresponding to a null gap: $E_g = 0$.

When $E_g = 0$ (figure 2) the super lattice corresponds to an equilibrium macro-state where it can be regarded as made of a mixture of micro domains or clusters where the average number of clusters with a stable and unstable magnetic state are equal. The system is increasingly stable that the number of stable clusters is larger. However, instability gains in absence of the anisotropy ($\Delta = 1$), for any exchange value. Whereas, for increasing anisotropy ($\Delta > 1$), the size of stability domain increases more and more that Δ increases. If the exchange ratio $J_\perp/J_\parallel$ increases, the macro-state is stable only if the magneto-crystalline anisotropy increases too. This result shows the important role of the anisotropy in the existence and stability of long range magnetic order in the studied super lattice as what is obtained in previous works [17; 18; 27].

We also obtained an estimation of the relaxation time τ_{mag} of magnetic elementary excitation states. Thus, basing on the fact that the contribution of the exchange to the created magnon frequency and therefore to the potential of mixture of iron 'd' and 's' bands corresponding to this creation V_{sd}^{mag} (measuring also the gap energy E_g) is related to the electronic contribution in a ratio of ten[28], we have: $V_{sd}^{mag} = \frac{m_e^*}{m_{mag}^*} V_{sd}^{ele} = 10^{-1} V_{sd}^{ele}$. The magnon relaxation time can then be written as: $\tau_{mag}^{-1} = \frac{2\pi}{\hbar} |V_{sd}^{mag}|^2\, \mathcal{D}_d(E_F)$. Where $\mathcal{D}_d(E_F)$ is the

density of states at the Fermi level. For iron $\mathcal{D}_d(E_F) = 4.16\ (eV^{-1})$ [29]. The values of E_g were calculated for different thicknesses t_{Fe} and they are in agreement with the mixture potential $V_{sd}^{mag} = 0.014\ eV$ given in literature [29; 30]. The obtained values for τ_{mag} according to E_g are gathered in table 1.

Table 1. The gap E_g of the created magnon state and the related relaxation time τ_{mag}.

t_{Fe} (Å)	E_g (eV)	τ_{mag} ($10^{-13}\ s$)
6 (3 planes)	0.008	0.411
10 (5 planes)	0.0114	0.202
14 (7 planes)	0.015	0.117
20 (10 planes)	0.018	0.081
30 (15 planes)	0.0195	0.062

The decrease of the $\tau(t_{Fe})$ with increasing magnetic thickness t_{Fe} suggests that the contribution of magnons to the system properties is more important for super lattices with finer magnetic layers. We notice moreover that the rate of decrease of $\tau(t_{Fe})$ is increasingly large that the magnetic layer is thicker reflecting the impact of the effect of volume compared with that of the interface. Surfaces and interfaces seem to support the created magnon states in these super lattices.

3.2. Magnetization per spin

3.2.1. The calculated magnetization

The total magnetization of a solid sample at a given temperature T is defined by:

$$M_Z(T) = g\mu_B < S^z >_T = g\mu_B\left[< S > - \sum_{k_{//}} < a^+_{k_{//}} a_{k_{//}} > \right]$$

For a super lattice made of N planes the average number of magnons is:

$$< a^+_{k_{//},l} a_{k_{//},l} > = \left[exp(\beta E_l\ (k_{//})) - 1 \right] \quad \text{with } l = 1,...\text{N}$$

The contribution of the spin waves to average magnetization by site of the super lattice is then given by:

$$m_z(T) = \frac{< S^z >}{S} = 1 - \frac{1}{S}\frac{1}{N}\frac{s}{(2\pi)^2}\sum_{l=1}^{N}\int_{BZ} < a_{l,k}a^+_{l,k} > dk_x dk_z$$

$$= 1 - \frac{1}{S}\frac{1}{\text{N}}\sum_{l=1}^{N}\frac{s}{(2\pi)^2}\int \frac{1}{\exp\left(\frac{E_l\ (k\ )}{k_B T}\right) - 1} dk_x dk_z \tag{10}$$

s is the surface of the elementary cell, k_B is the Boltzmann constant, BZ is the Brillouin zone and N is the number of atomic planes. $E_l(k)$ is the excitation spectrum for a mode l expressed by eq(8). The integral in the equation (10) can be analytically calculated in the range of the low temperatures $(T \leq T_C/3)$ where the principal contribution of the spin waves to the properties of the super lattice comes primarily from the modes of weak wave vectors $(ka = 2\pi a/\lambda \ll 1)$ allowing a development of $E_l^N(k)$ in the vicinities of zero. Let us take the new variables: $\zeta = k_x a$ and $\eta = k_z a$, giving $1 - cos(k_x a) \approx \frac{\zeta^2}{2}$ and $1 - \cos(k_z a) \approx \frac{\eta^2}{2}$. By introducing a transformation to the polar coordinates: $\rho^2 = \eta^2 + \zeta^2$ this development leads to an expression of the excitation spectrum:

$$E_l\ (k) = 8SJ_{//}(\Delta - 1) + 2J_{//}S\rho^2 + 2J_{\perp}S(1 + \varepsilon_1) \tag{11}$$

While incorporating (11) in the equation (10), one obtains:

$$m_z(T) = 1 - \frac{s}{4\pi NSJ_{\parallel}(2\pi)^2}k_B T\sum_{l=1}^{N}\log\left(- \frac{1}{e^{-\left(\frac{E_l\ (k\ )}{k_B T}\right)} - 1}\right) \tag{12}$$

In the limit of a macroscopic number of atomic planes $(N \to \infty)$, the super lattice becomes continuous and summation $\frac{1}{N}\sum_{l=1}^{N}$ is then replaced by $\frac{a}{2\pi}\int_{-\frac{\pi}{a}}^{\frac{\pi}{a}} dk_y$. In the same way, the term $2J_{\perp}S(1 + \varepsilon_l)$ i.e $4J_{\perp}S(1 - \cos(k_y a))$ describing the interactions between plans becomes $4J_{\perp}S(\frac{(k_y a)^2}{2})$ for $k_y a \ll 1$. Finally $m_z(T)$ is written:

$$m_z(T) = 1 - \frac{s}{4\pi NSJ_{\parallel}(2\pi)^2}k_B T\sum_{l=1}^{N}\ln\left(- \frac{1}{e^{-\left(\frac{E_l\ (k\ )}{k_B T}\right)} - 1}\right) \tag{13}$$

$E_l^N(k) = \Delta' + 2J_{\perp}S\zeta^2$ and $\Delta' = 8SJ_{\parallel}(\Delta - 1)$. An analysis of eq (13) in terms of the effect of the thermal excitation on the created magnon population gives:

(i) In the range of low temperatures such as the thermal excitation energy is very weak compared to the energy of created magnons: $k_B T \ll E_l(k)$ eq (13) is expressed by:

$$m_z(T) = 1 - \frac{1}{2}\left(\frac{\pi k_B^{3/2}}{2SJ_{\perp}}\right)^{1/2} \times g_{3/2}(z) \times \frac{s}{4\pi NJ_{\parallel}(2\pi)^2} \times T^{3/2} = 1 - B \times T^{3/2} \tag{14}$$

$g_{3/2}(z)$ is Bose's function and $z = e^{-\frac{\Delta'}{k_B T}}$ is the magnon gas fugacity. The contribution of gas of magnons

to the properties of the super lattice is significant for the limit of a great fugacity $(z \to 1)$. Thus, we note that the rate of magnetization evolves in a $T^{3/2}$-law as for 3D-systems (Bloch-law).

(ii) While if the width of the thermal excitation spectrum is more important than the energy of the created magnons such as: $\frac{k_B T_C}{3} \geq k_B T \gg E_l(k)$ (higher temperatures) magnetization by spin (13) becomes:

$$m_z(T) = 1 - \frac{k_B}{4\pi N 2SJ_{\parallel}} \times T \ln\left(\frac{2k_B}{(\Delta' + 4J_\perp S)(1+\sqrt{1-\left(\frac{4SJ_\perp}{\Delta' + 4J_\perp S}\right)^2}} \times T \right) \qquad (15)$$

We thus find a quasilinear behavior in $T \ln T$ as for the quasi-two-dimensional systems. The term in logarithm is due to the coupling between atomic planes. It diverges in absence of the anisotropy $(\Delta = 1)$ confirming the role of this one in the existence of a magnetic order in this type of systems. Indeed, by analyzing this logarithmic term in limit of an absence of the anisotropy, we have: $\Delta = 1$ implies $\Delta' = 0$ and $E_l^N(k) = 2J_\perp S\zeta^2$. The logarithmic term becomes then $\ln\frac{k_B T}{2J_\perp S} = \ln\frac{k_B T\zeta^2}{E_l^N(k)}$ which diverges if $E_l^N(k) \ll k_B T\zeta^2$ since $E_l^N(k) \ll k_B T$ and ζ^2 □ 1

3.3.2. Comparison between calculated and measured $m(T)$ results

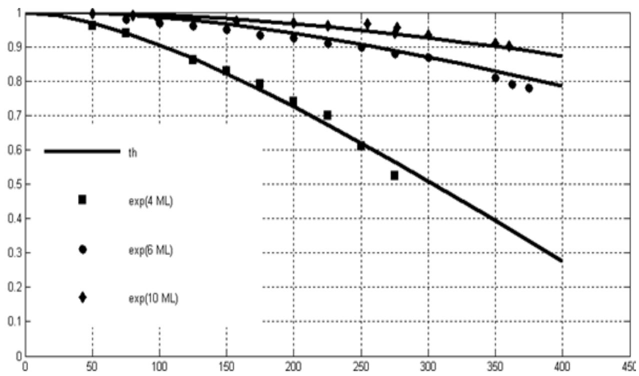


Figure 3 : Thermal variation of the magnetization per spin in super lattice [Fe /GaAs] for various thicknesses of the magnetic layer: $m_{calc}(T)$ (—) and $m_{mes}(T)$ (symbols) [5].

On figure 3, we show the results of our calculations for magnetization per spin $m_{calc}(T)$ (solid line) compared with measured values $m_{mes}(T)$ (symbols) obtained from the literature [5]. The adjustment of $m_{calc}(T)$ and $m_{mes}(T)$ values gives a very good agreement. What enabled us to deduce from the values of the exchange integral J (table 2) which are coherent with the values usually found for this type of super lattices. This good adjustment with the experiment suggests that the exchange is probably owing to the mixture of the s and d states of the iron atoms and mainly is of d character at the Fermi level. These d states are indeed rather localized, what is probably at the origin of this agreement with results calculated within the framework of an approximation with localized moments (Heisenberg model).

This agreement with the experiment confirm also that the thermal behavior of the magnetization $m(T)$ undergoes a dimensionality crossover (3D-2D) forwarding from a law in a $T^{3/2}$ for low temperatures (eq. (14)) as for 3-dimension systems to a quasilinear law in $T\,LnT$ (eq. (15)) of the 2-dimension systems when the temperature of the samples increases inside the range : $k_B T \leq \frac{k_B T_C}{3}$.

Table 2: Values of the exchange integrals deduced from the adjustment of $m_{calc}(T)$ with $m_{mes}(T)$ for various thicknesses of the Fe layer.

t_{Fe} (Å)	$J_{\parallel}$ (K)	$J_\perp$ (K)
6 (3 planes)	95	8
10 (5 planes)	155	15
14 (7 planes)	210	20
20 (10 planes)	270	35
30 (15 planes)	290	50

IV- The surface anisotropy and dipolar interaction effects

In the simultaneous presence of the surface anisotropy and dipolar interactions the magnetization per spin of the super lattices [Fe/GaAs] can be also studied using again the previous equation (10):

$$m(T) = \frac{<S_z>}{S} = 1 - \frac{1}{S}\frac{1}{N}\frac{s}{(2\pi)^2}\sum_{l=1}^{N}\int_{BZ} <a^+_{k_{//},l}a_{k_{//},l}> dk_x dk_y$$

The spectral theorem gives the average number $<a^+_{k,l}, a_{k,l}>$ in relation with the Green's functions $<<a^+_{k,l}, a_{k,l}>>$ such as:

$$< a_{k,l}^{+}\, a_{k,l} > = -2\int \frac{\mathrm{Im} << a_{k,l}^{+}\,, a_{k,l} >>}{e^{\beta E_l\,(k)} - 1}\, dk_x dk_y \tag{16}$$

where the Green's functions $G_{l,l} = << a_{k,l}^{+}, a_{k,l} >>$ are expressed in terms of the passage matrix P and its reverse P^{-1} allowing the resolution of the system of equations (5), as:

$$< a_{k,l}^{+}\, a_{k,l} > = \sum_{n=1}^{N} \left[\frac{P_{l\,n} P_{nl}^{-1} - P_{l\,n'} P_{n'l}^{-1}}{e^{\beta E_l\,(k)} - 1} - P_{l\,n'} P_{n'l}^{-1} \right] \tag{17}$$

So, magnetization per spin is given, for $n' = N + n$, by:

$$m(T) = 1 - \frac{1}{S}\frac{1}{N}\frac{s}{(2\pi)^2}\sum_{l=1}^{N}\sum_{n=1}^{N}\int_{BZ}\left[\frac{P_{l\,n}P_{nl}^{-1} - P_{l\,n'}P_{n'l}^{-1}}{e^{\beta E_l\,(k)} - 1} - P_{l\,n'}P_{n'l}^{-1}\right] dk_x dk_y \tag{18}$$

The expression (18) is more complex to establish analytically than when the exchange exists alone ($\alpha = D = 0$). We will limit ourselves to the numerical study of the combined effects of the surface anisotropy and the dipolar interactions. On the figure 4 we present a phase diagram describing the thermal evolution of the combined effects of the surface anisotropy α and dipolar Interactions D on the magnetic state of the super lattice [Fe/GaAs] through a thermal behavior of the magnetization rate $\rho_N(T,\, R)$ obtained as a ratio between $m(T)$ when these two factors α and D contribute differently ($R = \alpha / D \neq 1$) and $m(T)$ when α and D contribute with the same weight ($R = 1$) such as: $\rho_N(T,\, R) = \dfrac{m(T,\;\, R \neq 1)}{m(T,\;\, R = 1)}$

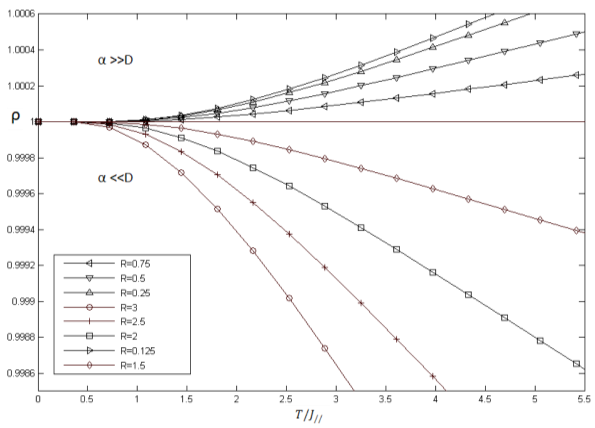


Figure 4: Thermal variation of magnetization rate: $\rho_N(T,\, R) = \dfrac{m(T,\;\, R \neq 1)}{m(T,\;\, R = 1)}$.

We note that when the surface anisotropy dominates ($R > 1$) magnetization decreases; whereas if the dipolar interactions are preponderant ($R < 1$), magnetization increases. Indeed, the anisotropy aligns the magnetic moments perpendicular to the film plane, whereas the dipolar interactions tend to align these moments parallel to the film and consequently favours magnetization in plane and reinforces the stability of the magnetically ordered state.

V- Conclusion

In this work, we studied the contribution of the spin wave excitations to the properties of the magnetic super lattice [Fe/GaAs], for various thicknesses of the magnetic layer. We established a corresponding Heisenberg hamiltonian taking into account, in addition to the direct magnetic exchange, of the anisotropy and dipolar interactions. The technique of Green's functions was used to diagonalize this hamiltonian.

The excitation spectrum $E_l^N(k)$ and magnetization by spin $m(T)$ are calculated analytically when the magnetic exchange is taken into account alone. The existence of an excitation gap E_g of magnons is highlighted. E_g depends on the anisotropy confirming the role played by the anisotropy in the stability of the long range magnetic order in [Fe/GaAs].

A good agreement between $m(T)$ calculated and measured is obtained. The deduced values of the exchange integrals are comparable with the values known for this type of magnetic super lattices. The evolution of $m(T)$ presents a crossover of dimensionality (3D-2D); it passes from a law in $T^{3/2}$ to a law in $T \ln T$ when T increases. The study of the combined effect of the surface anisotropy α and of the dipolar interactions D confirms the importance of the anisotropy in the reinforcement of stability and the long distance magnetic order in the studied super lattice.

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