ORIGINAL PAPER

NEW DEVELOPMENTSTO STUDY AT LOWTEMPERATURE THE EFFECT OF MAGNETIZATION AND MAGNETIC ANISOTROPY

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Abstract*.Research in the field of materials sciences and in particular in the field of magnetic thin films and multilayers has gained considerable momentum thanks to the economic stakes involved in magnetic and magneto-optical recording. Hard disks, magnetic tapes, and optical disks are today the main media used in computers. The most promising multi-layer or alloy systems are those with high perpendicular magnetic anisotropy and excellent resistance to oxidation and corrosion. It is clear, however, that the future use of such supports for high-density magneto-optical recording requires an accurate understanding of the mechanisms responsible for the observed magnetic*
Keywords*: magnetic, multilayers,high-density magneto-optical recording.*

1. INTRODUCTION

Multi-layer films with alternating ferromagnetic and non-magnetic layers can show strong perpendicular anisotropy. This has been attributed to the effects of symmetry breaking at the interface between layers [1]. If the relative number of true atoms is reduced relative to the number of interface atoms by thin film growth, the magnetization of the film becomes oriented perpendicularly. In particular, the Ni / Pt multilayers (Nikel / Platinum) with very thin layers of Ni (≤34 Å) show perpendicular anisotropy and have been intensively researched since their discovery [2, 3]. These materials have been proposed as new candidates for a magneto-optical recording medium, replacing the rare-transition metal alloys. Advantages of multilayers include their increased resistance to oxidation, the potential for storage densities greater than short wavelengths, and the ability to customize the magnetic properties of multilayers by simply varying the thickness, layer thickness,Or growth conditions [4].

Several theoretical studies have shown that the magnetic behavior of a ferromagnetic layer depends essentially on competition between anisotropy and dipole interaction. In this model, we show that anisotropy and exchange interactions destabilize the magnetic order. This model takes into account the thickness of the crystal structure, the exchange of interactions between nearest neighbors and surface and volume anisotropy. But initially we will neglect the anisotropy.

The model we propose is based on the theory of spin waves, using the Holstein Primakoff formulation to compute the spin wave excitation spectrum and the thermal variation of the magnetization in ferromagnetic thin and multilayer layers. This model also allows us to calculate the variation of the coefficient of the spin waves $B_{3/2}$ as a function of the thickness t.

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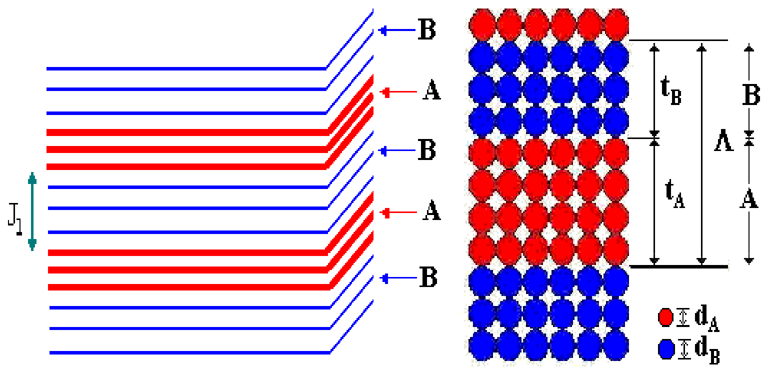
2. EXPERIMENTAL

In this paper, we describe our studies on multilayer Ni / Pt prepared by the electron beam evaporation method. The Ni / Pt magnetization of the multilayers was measured as a function of temperature. A simple theoretical model based on a ferromagnetic anisotropic system was used to explain the temperature dependence of the magnetization M (T) and the approximate values for the exchange interaction. From the effect of the thickness of the non-magnetic layers on the behavior of the temperature, it is possible to obtain information on a possible interlayer coupling. The behavior of M (T) and the Curie temperature T_C will not be determined by interlayer coupling, but by the interaction between anisotropy [5].

3. RESULT AND DISCUSS

The proposed system can be considered periodic and realized by the alternative deposition of the magnetic metals (A) forming a layer of thickness t_A and non-magnetic metals (B) forming a layer of thickness t_B. It is assumed in this study that the multilayer system has an abrupt interface and verifies the following assumptions:

- Each magnetic layer is composed of n ferromagnetic atomic planes, the mesh parameter of the network is equal to a.
- Each magnetic layer will be repeated times defining a super period.
- The exchange interaction between the spins of the same atomic plane, as well as between the adjacent planes, is denoted by J_0.
- The exchange interaction between the spins of the same atomic plane for the first and last plane is denoted J_S.
- The magnetic coupling between two adjacent ferromagnetic planes, separated by a distance c, is represented by J_1.



The Heisenberg Hamiltonian of our system is written as follows:

$$H = H_1 + Has + Hav$$

with: H_1 describes the exchange interactions at the surface and those of the volume; has and Hav are respectively the contribution of surface and volume anisotropy. They are given by:

$$H_1 = -J_0 \sum_{\substack{i,j \\ \nu=2\ldots n-1 \\ \mu=1\ldots\tau}} \vec{S}_{\mu,\nu,i}\vec{S}_{\mu,\nu,j} - J_0 \sum_{\substack{i\in\nu, j\in\nu' \\ \nu=2\ldots n-1, \\ \nu'=\nu+1 \\ \mu=1\ldots\tau}} \vec{S}_{\mu,i\in\nu}\vec{S}_{\mu,j\in\nu'} - J_S \sum_{\substack{i\in\nu, j\in\nu' \\ \nu=1,n \\ \nu'=\nu+1 \\ \mu=1\ldots\tau}} \vec{S}_{\mu,i\in\nu}\vec{S}_{\mu,j\in\nu'} - J_1 \sum_{\substack{i\in\nu_{P_I}, j\in\nu_{P_S} \\ \mu=1\ldots\tau}} \vec{S}_{\mu,i\in\nu_{P_I}}\vec{S}_{\mu,j\in\nu_{P_S}}$$

$$H_{as} = D_S^{\perp} \sum_{\substack{i \\ \nu=1,n \\ \mu=1\ldots\tau}} \vec{S}^{Z^2}_{\mu,\nu,i} + D_S^{//} \sum_{\substack{i \\ \nu=1,n \\ \mu=1\ldots\tau}} \left(\vec{S}^{X^2}_{\mu,\nu,i} - \vec{S}^{Y^2}_{\mu,\nu,i} \right)$$

$$H_{av} = D_b^{\perp} \sum_{\substack{i \\ \nu=2\ldots n-1 \\ \mu=1\ldots\tau}} \vec{S}^{Z^2}{}_{\mu,\nu,i} + D_b^{//} \sum_{\substack{i \\ \nu=2\ldots n-1 \\ \mu=1\ldots\tau}} \left(\vec{S}^{X^2}{}_{\mu,\nu,i} - \vec{S}^{Y^2}{}_{\mu,\nu,i} \right)$$

P_I and P_S : Represent the indices of the planes separated by the non-magnetic substance B.
$D_S^{\perp}$ and $D_S^{//}$ Are respectively the parameters of surface anisotropy perpendicular and parallel.
$D_b^{\perp}$ and $D_b^{//}$ Are respectively the parameters of anisotropy of perpendicular and parallel volume.

By introducing the well-known operators in the formulation of Holstein Primakoff [6]:

$$S^+_{\mu,\nu,j} = S^{\mu,\nu,j}_x + i\, S^{\mu,\nu,j}_y \text{ et } S^-_{\mu,\nu,j} = S^{\mu,\nu,j}_x - i\, S^{\mu,\nu,j}_y$$

And checking the respective switching relationships:

$$[S^{\mu,\nu,j}_z, S^+_{\mu',\nu',j}] = \delta_{i,j}\, \delta_{\nu,\nu'}\, \delta_{\mu,\mu'}\, S^+_{\mu,\nu,j} \; ; \; [S^{\mu,\nu,j}_z, S^-_{\mu',\nu',j}] = \delta_{i,j}\, \delta_{\nu,\nu'}\, \delta_{\mu,\mu'}\, S^-_{\mu,\nu,j}$$

$$\text{et } [S^+_{\mu,\nu,j}, S^+_{\mu',\nu',j}] = 2\delta_{i,j}\, \delta_{\nu,\nu'}\, \delta_{\mu,\mu'}\, S^{\nu,j}_z$$

The spin operators are linked to the creation $a^+_{\mu,\nu,j}$ and annihilation $a_{\mu,\nu,j}$ operators by the following relations:

$$S^+_{\mu,\nu,j} = \sqrt{2S}\; f_{\mu,\nu,j}(S)\, a_{\mu,\nu,j}\,,\; S^-_{\mu,\nu,j} = \sqrt{2S}\, a^+_{\mu,\nu,j}\; f_{\mu,\nu,j}(S) \text{ and } S^{\mu,\nu,j}_z = S - a^+_{\mu,\nu,j}\, a_{\mu,\nu,j}$$

$$f_{\mu,\nu,j}(S) = \sqrt{1 - \frac{a^+_{\mu,\nu,j}\, a_{\mu,\nu,j}}{2S}}$$

In addition, the creation $a^+_{\mu,\nu,j}$ and annihilation $a_{\mu,\nu,j}$ operators, for each atomic spin, satisfy the following commutation rules [7]:

$$a_{\mu,\nu,i}\, a^+_{\mu',\nu',j} - a^+_{\mu,\nu,i}\, a_{\mu',\nu',j} = \delta_{\mu,\mu'}\, \delta_{\nu,\nu'}\, \delta_{i,j}$$

$$a_{\mu',\nu,i}\, a_{\mu',\nu',j} - a_{\mu',\nu',j}\, a_{\mu',\nu,i} = a^+_{\mu,\nu,i}\, a^+_{\mu',\nu',j} - a^+_{\mu',\nu',j}\, a^+_{\mu,\nu,i} = 0$$

By substituting the spin operators by the creation and annihilation operators, the sum of the products of the spin operators will become:

$$\sum_{i_\nu ; j_{\nu'}} \vec{S}_{i_\nu} \vec{S}_{j_{\nu'}} = S^2 \sum_{i_\nu ; j_{\nu'}} - 2S \sum_{i_\nu ; j_{\nu'}} a^+_{i_\nu} a_{i_\nu} + 2S \sum_{i_\nu ; j_{\nu'}} a^+_{i_\nu} a_{j_{\nu'}}$$

By introducing the Fourier transform : $a_{j_{\nu_\mu}} = \frac{1}{\sqrt{N_T}} \sum_{\vec{k}} a_{\vec{k}} e^{i\vec{k}\vec{r}_{i_{\nu_\mu}}}$

Where N_T is the total number of cells constituting the magnetic layer of the multilayer, given by:

$$N_T = \tau \times n \times N$$

With τ the number of magnetic monolayers, n the number of ferromagnetic monoatomic planes in each monolayer and N the number of atomic sites per ferromagnetic plane constituting the magnetic substance A.

After performing the various appropriate transformations, we find the following results:

$$\sum_{i_{\nu_\mu} ; j_{\nu'_{\mu'}}} \vec{S}_{i_{\nu_\mu}} \vec{S}_{j_{\nu'_{\mu'}}} = S^2 \sum_{i_{\nu_\mu} ; j_{\nu'_{\mu'}}} + 2S \sum_{\vec{k}} \sum_{\vec{r}} (e^{i\vec{k}\vec{r}} - 1) a^+_{\vec{k}} a_{\vec{k}}$$

• **Calculation of magnetization:**

Thermal agitation produces a variation in the total magnetization of the multi-layer which is given by:

$$M_z(T) = g\ \mu_B \sum_{\mu,\nu,j} \left\langle S_z^{\mu,\nu,j} \right\rangle_T$$

where **g** is the *Landé* factor and where $\boldsymbol{\mu_B}$ is the *Bohr* magneton.

In terms of the spin deflection operator, $S - S_z^{\mu,\nu,j}$,magnetization can be written:

$$M_z(T) = g\ \mu_B \left\{ \langle S \rangle_T - \sum_{\vec{k}} \left\langle a^+_{\vec{k}} a_{\vec{k}} \right\rangle_T \right\}$$

In the theory of spin waves, the thermal agitation of the magnetic moments of a ferromagnetic is described by independent and incoherent magnons; The magnons behave like bosons, their numbers are not conserved and consequently their chemical potential is zero. It follows that for low temperatures, the spin deviation operators meet the statistical ***Bose - Einstein***, the magnetization then write:

$$M_z(T) = g\ \mu_B \left\{ N_T S - \sum_{\vec{k}} \frac{1}{e^{\beta\varepsilon(\vec{k})} - 1} \right\}$$

By replacing the $\vec{k}$ by integrating within the first *BRILLOUIN* zone, the magnetization is given by:

$$M_z(T) = M_z(0) - \frac{g\ \mu_B V_T}{8\pi^3} \int_{z.B.} \frac{1}{e^{\beta\mathcal{E}(\vec{k})} - 1} d^3\vec{k}$$

The total volume occupied by the magnetic substance in our representation will then be:

$$V_T = \tau N \left\{ (n-1)\frac{V_M}{3} + \frac{V_M^{'}}{3} \right\} = N_T \frac{a^3}{4} \left\{ m + \frac{\sqrt{3}}{n}\frac{c}{a} \right\} = N_T \frac{a^3}{4} \left\{ 1 + \frac{\sqrt{3}}{n}\frac{t_B}{a} \right\}$$

where:

$$V_M = \frac{3}{4} a^3 \quad , \quad m = 1 - \frac{1}{n} \quad \text{and} \quad V_M^{'} = \frac{3\sqrt{3}}{4} a^2 c$$

the introduction of $\vec{k}$ is permitted for a very large number of sites in which the componentsof $\vec{k}$ Vary in an almost continuous manner in this case.

A .Cas of τ 1-layer ferromagnetic layer atomic:

a : At low approximations

We can rewrite the magnetization in the form:

$$M_z(T) = M_z(0) \left[1 - \frac{v}{8\pi^3 S} \int_{z.B} \frac{e^{-\beta \mathcal{E}(\vec{k})}}{1 - e^{-\beta \mathcal{E}(\vec{k})}} d^3\vec{k} \right]$$

with:

$$v = \frac{V_T}{N_T} = \frac{\sqrt{3}\, a^2 c}{4} = \frac{a^3}{4} \left\{ 1 + \sqrt{3}\frac{t_{Pt}}{a} \right\}$$

At the approximation of long wavelengths and very low temperatures, the term $e^{-\beta \mathcal{E}(\vec{k})}$ becomes very small and we can replace $\left[1 - e^{-\beta \mathcal{E}(\vec{k})}\right]^{-1}$ by 1. The magnetization will then be written

$$M_z(T) \cong M_z(0) \left[1 - \frac{\sqrt{3}\, a^2 c}{32\pi^3 S} \int_{z.B.} e^{-\beta \mathcal{E}(\vec{k})} d^3\vec{k} \right]$$

Integrating this expression with respect to variable k_x and k_z gives us:

$$\mathrm{M}_z(\mathrm{T}) \cong \mathrm{M}_z(0) \left[1 - \frac{\sqrt{3}\, k_B T}{24\pi^2 J_s S^2} c \int_0^{\pi/c} \mathrm{e}^{-4\beta S J_1 [1 - \cos(k_y c)]} \mathrm{dk}_y \right]$$

To simplify the rest of the calculations we will ask:

$$\theta_0 = \frac{24\pi J_S S^2}{k_B}, \ \theta_1 = \frac{4\ J_1 S}{k_B}, \ \theta_0 = 6\pi S \Lambda \theta_1, \ \Lambda = \frac{J_S}{J_1}$$

a.1: In the temperature range $T << \theta_1$ **:**

The magnetization Will be given as a first approximation by:

$$M_z(T) \approx M_z(0)\left[1 - 3\sqrt{S\Lambda}\left(\frac{T}{\theta_0}\right)^{3/2}\right] \quad \text{Or again: } M_z(T) \approx M_z(0)\left[1 - B^0_{3/2}\, T^{3/2}\right]$$

Or $B^0_{3/2}$, The constant of the spin waves, is given in this case by:

$$B^0_{3/2} = \frac{3\sqrt{\Lambda S}}{\theta_0^{3/2}} = \frac{\sqrt{6}}{96\, S\, \pi^{3/2}}\left(\frac{k_B}{S\, J_S}\right)^{3/2}\sqrt{\frac{J_S}{J_1}}$$

a.2: In the temperature range $\theta_1 << T << \theta_0$

The magnetization can be written: $M_z(T) \cong M_z(0)\left[1 - B\, T\, e^{-\frac{\theta_1}{T}}\right]$

where the constant B is given by: $B = \dfrac{\sqrt{3}}{\theta_0} = \dfrac{\sqrt{3}\, k_B}{24\pi\, J_S\, S^2}$

Or by replacing the exponential term $e^{-\Theta_1}$ by the unit $M_z(T) \approx M_z(0)\left[1 - BT\right]$ which gives rise to a linear dependence of the magnetization as a function of the temperature.

b: Improved approximations:

All calculations we have undertaken since the relation (24) and to the relationship (46), were allowed by the term identification $\left[1 - e^{-\beta\,\mathcal{E}(\vec{k})}\right]^{-1}$ To 1. Now, and in the series of calculations, we will develop this term in powers of $e^{-\beta\,\mathcal{E}(\vec{k})}$, is: $\left[1 - e^{-\beta\,\mathcal{E}(\vec{k})}\right]^{-1} = \sum_{r=0}^{\infty} e^{-r\beta\,\mathcal{E}(\vec{k})}$

b.1: In the temperature range $T << \theta_1$ **:**

The magnetization is given by : $M_z(T) = M_z(0)\left[1 - 3\,\zeta(3/2)\sqrt{S\Lambda}\left(\frac{T}{\theta_0}\right)^{3/2}\right]$

where **ζ(x)** is ***the Riemann function***, equal to ***x=3/2* à *2.612***.
The constant spin wave B 3/2 will be equal to:

$$B_{3/2} = \zeta(3/2)\, B^0_{3/2} = 3 \times \zeta(3/2)\frac{\sqrt{\Lambda S}}{\theta_0^{3/2}} = \frac{2.612\sqrt{6}}{96\, S\, \pi^{3/2}}\left(\frac{k_B}{S\, J_S}\right)^{3/2}\sqrt{\frac{J_S}{J_1}}$$

The constant spin waves of a massive even crystallographic nature would then be expressed as: $B_{3/2}(massif) = \dfrac{3\zeta(3/2)}{4}\dfrac{\sqrt{3S}}{\theta_0^{3/2}} = \dfrac{2.612\sqrt{2}}{128\,\pi^{3/2}\, S}\left(\dfrac{k_B}{S\, J_S}\right)^{3/2}$

it is interesting to note that, compared to that of a massive even crystallographic nature; value of the constant spin waves of a single layer must be larger:

$$B_{3/2}(monolayer) = \frac{4\sqrt{3\Lambda}}{3}\ B_{3/2}(massif)$$

b.2 : In the temperature range $\theta_1 << T << \theta_0$

The magnetization can be written:

$$\mathrm{M_z(T)} \cong \mathrm{M_z(0)}\left[1 - \frac{\sqrt{3}\ k_B\, T}{24\,\pi\, S^2\, J_S}\ \ln\left(1 - e^{-\frac{4 J_1 S}{k_B T}}\right)^{-1}\right]$$

B: Cas of τ ferromagnetic layer at n atomic planes

B.1. In the temperature range $T << \theta_1$ **:**

The magnetization is given in first approximation by:

$$\mathrm{M_z(T)} \cong \mathrm{M_z(0)}\left[1 - \xi\left(\frac{3}{2}\right)\frac{(k_B T)^{\frac{3}{2}}}{16\,(S\pi)^2 C\sqrt{2S\, n\,\tau J_1}}\ \frac{\left[m + \frac{\sqrt{3}}{n}\frac{c}{a}\right]}{\sqrt{\frac{4}{3} m\Lambda + \frac{1}{n}\left(\frac{c}{a}\right)^2}}\right]$$

$$C = \frac{mn}{2} + 3(\mathrm{J_0}(\frac{mn-1}{2}) + \mathrm{J_S})$$

This relationship allows us to recover the magnetization as well that of a magnetic layer as a massive epitaxy in the same direction [111]. Indeed, we can rewrite $B_{3/2}$ (n), according to the constant spin wave of massive $B_{3/2}$ (solid), as follows:

$$\mathrm{B}_{3/2}(n) \cong \frac{(k_B\theta_0)^{\frac{3}{2}}}{12 S^3\pi^2 C\sqrt{6n\,\tau J_1}}\ \frac{\left[m + \frac{\sqrt{3}}{n}\frac{c}{a}\right]}{\sqrt{\frac{4}{3} m\Lambda + \frac{1}{n}\left(\frac{c}{a}\right)^2}}\ \mathrm{B}_{3/2}(massif)$$

B.2. In the temperature range $T \le \frac{T_C}{3}$:

The magnetization in this case will be given by:

$$\mathrm{M_z(T)} \cong \mathrm{M_z(0)}\left[1 - \frac{K_B^{\frac{3}{2}}}{32(S\pi)^2 C} T^{\frac{3}{2}} \sqrt{\frac{3}{2\pi n\tau}}\ \frac{\left[m + \frac{\sqrt{3}}{n}\frac{c}{a}\right]}{\sqrt{m}} \sum_{\nu=1}^{\infty} \frac{e^{-\left[\frac{4S\tau\nu}{K_B}\frac{J_1}{T}\right]}}{\nu^{3/2}} \left\{1 + \left[\frac{4\sqrt{2}S\tau\nu\pi}{K_B^{\frac{3}{2}}}\frac{J_1}{T}\right] e^{-\left[\frac{3}{32\, mn\tau\nu}\left(\frac{c}{a}\right)^2 T\right]}\right\}\right]$$

We find that theoretically and considering only the ferromagnetic coupling, starting from two ferromagnetic atomic planes, the behavior Quasi-linear temperature magnetization of the system does not appear; the predominant term remains the term $T^{3/2}$, imposed by neighboring ferromagnetic plans.

Calculation of constant pseudo-spin-wave and v is their interaction :

We repeated adjustment of the experimental points by our relationship wherein the proportionality coefficient to $T^{3/2}$ or"constant" spin waves fluctuate with temperature. Fromthis relationship and assigning the value of spin S = 0.5, then the lattice parameter $a = a_{Ni}$ of nickel and the thickness of the nonmagnetic layer t_{Pt} platinum values the 3.52 Å and 18 Å, respectively, we deduced the "values" of the ferromagnetic exchange interaction J_0 between nearest neighbors of atoms of nickel and that of the interlayer magnetic coupling J_1 neighboring magnetic planes, in accordance with the experimental values M_S of sample magnetization (see Table 1).

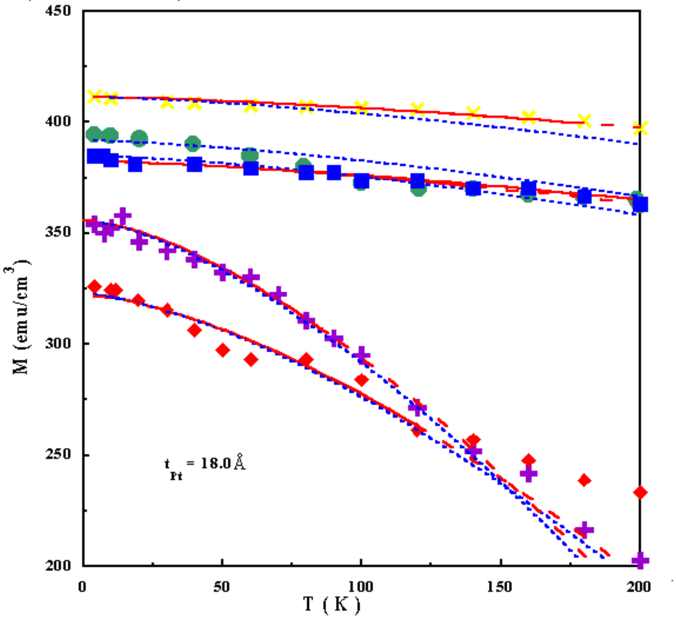


Figure1. The adjustment of the magnetization curves of the different magnetic multilayers *Ni/Pt*, Thickness: t_{Ni} = *13.3 Å*(), *15.4 Å*(◆), *21 Å*(■), *24 Å*(●), *28 Å*(✕).

Table 1. Exchange the appropriate results of the interaction J_S and magnetic interlayer coupling J_1.

t_{Ni} (Å)	J_S / k_B (K)	J_1 / k_B (K)
21	180	10^{-4}
24	180	10^{-3}
28	197	0.3

The exchange interaction values obtained do not coincide with the expected range relative to the exchange interaction of the massive nickel that is around *248 K*. However, magnetic interlayer coupling J_1 Is low in comparison with the coupling J S between the nearest neighbors of a single magnetic layer for multilayer Ni/Pt, the thickness of the nickel is less than 16.8 Å, and still substantially lower for larger thicknesses. This discrepancy between the values of J_S for low thicknesses and large thicknesses means that the values found do not reflect the true values of the magnetic coupling, but the actual values, which must take account of the anisotropy.

Checking the value of the spin wave constant

By plotting these values in the expression of the constant spin waves defined from equation (B.1), we find the values compiled in Table 2. In all cases, the behavior observed for temperatures $\frac{T_C}{3}$, remains the same showing qualitatively that the constant spin wave $B_{3/2}$ decreases the thickness of the nonmagnetic layer and the values obtained are greater than the value $7.5\times10^{-6}\ K^{-3/2}$ found for the massive nickel; indeed describes our relationship well, at least qualitatively, this physical aspect. This last relation shows that the reduction of the thickness of the magnetic layer is reflected on the fluctuation of the constant spin wave $B_{3/2}$, and consequently by a decrease in the magnetization of the multilayer; remembers that this calculation is not taken into account the anisotropy.

Table 2. Values of the constant spin waves of the samples studied for different thicknesses.

t_{Ni}(Å)	$B_{3/2}(10^{-6}K^{-3/2})$
21.0	24.3 ± 8.2
24.0	22.8 ± 5.3
28.0	18.2 ± 3.4

We have seen that the constant spin wave varies substantially linearly as a function of $1/t_{Ni}$. This approximat τ ion is good enough for multilayers whose thickness of the magnetic layer is sufficiently large. For this we plot the variation of the constant $B_{3/2}$, in function of the inverse of the thickness of the magnetic layer ($1/t_{Ni}$), for samples whose thickness varies in the range $10.5 \leq t_{Ni} \leq 28$ Å, deposited at300K on a platinum thickness of buffer layer 100 Å (Figure 2).

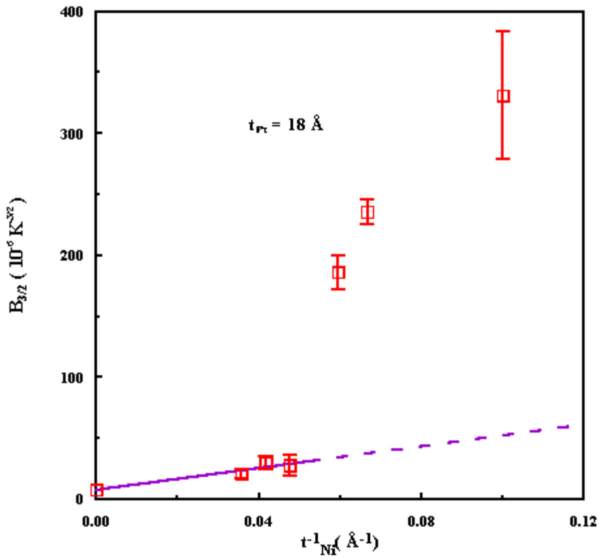


Figure 2. Changes in the constant of spin waves $B_{3/2}$ in function of the inverse of the thickness of the magnetic layer ($1/t_{Ni}$).

We found that some experimental aspects concerning the low thickness of the magnetic layer of nickel deviate from the straight right as we have under our model. But this deviation is more important than expected, which leads us to confirm that there is a change in the observed properties of the multilayers and that could be due either to a high excitation of the spin waves due to the polarization of platinum or to a change in the structure or effect of the interface anisotropy.For samples with the thickness t_{Ni} is such that: $21 \leq t_{Ni} \leq 28$ Å, we note that the values of the constant spin wave $B_{3/2}$ decreases the thickness of the magnetic layer according to the law we have established above, or even:

$$B_{3/2}(t_{Ni}) = B_{massif} + \frac{B_{surface}}{t_{Ni}}$$

where B_{massif} is the constant spin wave of massive nickel.

It follows that it is the constant B surface due to surface effects, we can bind to the effects of interface anisotropy strongly affecting the magnetization of the arm according to the thickness and consequently to Its orientation.

The right adjusting the values of the constants of spin waves relating to thickness $t_{Ni} \geq 21$ Å, gives us $B_{surface}=(2193 \pm 195)\times 10^{-6}\ K^{-3/2}$Å, and the extrapolated value à $t_{Ni}^{-1} = 0$, gives us $B_{massif} = 7.6\times 10^{-6}\ K^{-3/2}$, in good agreement with that found for the massive nickel that is about $7.5\times 10^{-6}\ K^{-3/2}$.

CONCLUSION

We have developed a model for the study of spin waves into account the crystallographic orientation, the thickness of the magnetic layer and the thickness of the spacer layer between two magnetic layers. This model will allow us to calculate the effective values of interlayer interchanges and magnetic interlayer interactions; and thereby to provide the variation of the constant Bloch ($B_{3/2}$according to the number of atomic layers forming the ultrathin.

In the next study, our work will be dedicated at the effect of anisotropy on the magnetic behavior of two-dimensional structures

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