BULK SPIN WAVES PROPAGATION IN DIRECTION PERPENDICULAR TO THE (110) PLANE FOR FERROMAGNETIC SUPERLATTICE

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A superlattice consisting of alternating layers of two-simple Heizenberg ferromagnetic is considered. Using Green function method the dispersion equations of bulk spin waves propagation in direction perpendicular to the plane (110) are derived for this systems. The numerical results are shown graphically.

During the past decade, there has been considerable effort devoted to the synthesis and study of composite materials, and of superlattices formed from alternating layers of different materials [1-3]. The study of spin waves is very useful in determining the fundamental parameters that characterize magnetic superlattice. In magnetic superlattices, elementary excitations have properties distinctly different from the modes associated with any one constituent. Bulk spin waves of periodic structure or magnetic superlattices have been analyzed theoretically in many special cases [4-6]. In the short-wavelength limit, where the exchange coupling is dominant, comparatively fewer studies have been done. Some qua1itative features of superlattice are most easily explained for the simple – cubic structure in terms of modified single - film properties. The bulk spin-wave regions in simple-cubic Heisenberg ferromagnetic material are derived in Ref.[4] The aim of this paper is to study by the Green function method [7,8] properties of an ferrormagnetic superlattice with quantum Heisenberg spins at finite temperature and this theoretical studies are analogous to one from the Ref.[9], where bulk spin waves propagation in direction perpendicular to the plane (001) in ferromagnetic superlattice is considered.

As indicated in fig. 1 we consider in this paper a simple cubic ferromagnetic superlattice model in which the atomic planes of material 1 alternate with atomic planes of material 2. The materials are taken to be simple – cubic Heisenberg ferromagnetic, having exchange constant J_1 and J_2 and lattice constant a.

We consider here the following Heisenberg Hamiltonian:

$$H = -\frac{1}{2}\sum_{i,j} J_{ij}\left(S_i S_j\right) - \sum_i g\mu_\beta\left(H_0 + H_i^{(A)}\right)S_i^z \qquad (1)$$

where J_{ij} -represents the exchange between the spins S_i and S_j of the nearest neighbors. H_0 is an applied magnetic field in the superlattice z direction, and $H_i^{(A)}$ (i =1,2) anisotropy field for a ferromagnetic with simple unaxial anisotropy along the z axis. We define a double – time Green function in real space $G_{ij}(t,t') = \langle\langle S_i^+(t); S_j^-(t')\rangle\rangle$.

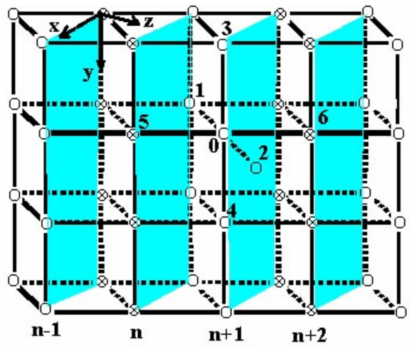

Fig. 1 A simple cubic ferromagnetic superlattice model in which the atomic planes of material 1 alternate with atomic planes of material 2. The same lattice parameter a is assumed for all materials.

We consider here the following Heisenberg Hamiltonian:

$$H = -\frac{1}{2}\sum_{i,j} J_{ij}\left(S_i S_j\right) - \sum_i g\mu_\beta\left(H_0 + H_i^{(A)}\right)S_i^z \qquad (1)$$

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$$G_{i,j}(t,t') = \frac{1}{\pi^2}\int dk_{||}\, exp[ik_{||}(r_i - r_j)]\,\frac{1}{2\pi}\int d\omega G_{nn'}(\omega,k_{||})\,exp[-i\omega(t-t')] \qquad (2)$$

where $k_{||}$ is two-dimensional wave vector, ω is spin-wave frequency, n and n' indices of the layers to which r_i and r_j and belong, respectively.

$$\begin{cases}(\omega - A_1)G^{(1)}_{n,n'} + J_1\langle S_1^z\rangle tG^{(1)}_{n+1,n'} + J\langle S_1^z\rangle t^*G^{(2)}_{n+1,n'} + J_1\langle S_1^z\rangle t^*G^{(1)}_{n-1,n'} + J\langle S_1^z\rangle tG^{(2)}_{n-1,n'} = 2\langle S_1^z\rangle\delta_{n,n'} \\ (\omega - A_2)G^{(2)}_{n,n'} + J_2\langle S_2^z\rangle tG^{(2)}_{n+1,n'} + J\langle S_2^z\rangle t^*G^{(1)}_{n+1,n'} + J_2\langle S_2^z\rangle t^*G^{(2)}_{n-1,n'} + J\langle S_2^z\rangle tG^{(1)}_{n-1,n'} = 2\langle S_2^z\rangle\delta_{n,n'}\end{cases} \quad (3)$$

where

$$A_{1(2)} = g\mu_B\left(H_0 + H^{(A)}_{1(2)}\right) + 4J_{1(2)}\langle S^z_{1(2)}\rangle + 2J\langle S^z_{2(1)}\rangle - 2J_{1(2)}\langle S^z_{1(2)}\rangle cos\left(k_y a\right),$$
$$t = exp\left(ik_x a/\sqrt{2}\right),\ t^* = exp\left(-ik_x a/\sqrt{2}\right)$$

The system is also periodic in z direction which lattice constant is $a/\sqrt{2}$. According Bloch's theorem we can write

$$G^{(1),(2)}_{n+1,n'} = exp\left(ik_z a/\sqrt{2}\right)G^{(1),(2)}_{n,n'} = TG^{(1),(2)}_{n,n'} \quad (4)$$

Using (4) the system of equation of (3) can be written the following matrix form

$$\begin{pmatrix}\omega - A_1 + J_1\langle S_1^z\rangle\left(tT + t^*T^*\right) & J\langle S_1^z\rangle\left(t^*T + tT^*\right) \\ J\langle S_2^z\rangle\left(t^*T + tT^*\right) & \omega - A_2 + J_2\langle S_2^z\rangle\left(tT + t^*T^*\right)\end{pmatrix}\cdot\begin{pmatrix}G^{(1)}_{n,n'} \\ G^{(2)}_{n,n'}\end{pmatrix} = \begin{pmatrix}2\langle S_1^z\rangle\delta_{n,n'} \\ 2\langle S_2^z\rangle\delta_{n,n'}\end{pmatrix} \quad (5)$$

The dispersion of equation for the bulk spin waves propagating in direction perpendicular to the plane (110) for the superlattice under consideration is derived by the equation (5) as following form:

$$\omega^2 + \omega\left\{2cos\left(a\left(k_x + k_z\right)/\sqrt{2}\right)\left(J_1\langle S_1^z\rangle + J_2\langle S_2^z\rangle\right) - A_1 - A_2\right\} + \left(2J_1\langle S_1^z\rangle cos\left(a\left(k_x + k_z\right)/\sqrt{2}\right) - B_1\right)\times$$
$$\times\left(2J_2\langle S_2^z\rangle cos\left(a\left(k_x + k_z\right)/\sqrt{2}\right) - B_2\right) - 4J^2\langle S_1^z\rangle\langle S_2^z\rangle\left(cos\left(a\left(k_x - k_z\right)/\sqrt{2}\right)\right)^2 = 0 \quad (6)$$

The equation (6) is the main results of this paper. It can be verified from equation (6) that when both media are identical it reduces to dispersion equation of bulk spin waves propagation in direction perpendicular to the plane (110) for ferromagnetic constituents [4,5].

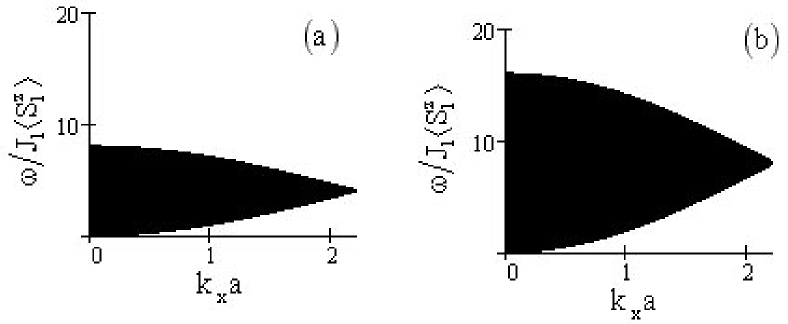

Fig 2 Bulk spin-wave regions for (a) the constituents 1 and (b) constituents 2 with the parameters $J_2/J_1 = 2$; $g_1 = g_2$; $g_1\mu_B H_0/J_1\langle S_1^z\rangle = 0.05$, $g_1\mu_B H_1^{(A)}/J_1\langle S_1^z\rangle = 0.01$; $g_2\mu_B H_2^{(A)}/J_1\langle S_1^z\rangle = 0.03$.

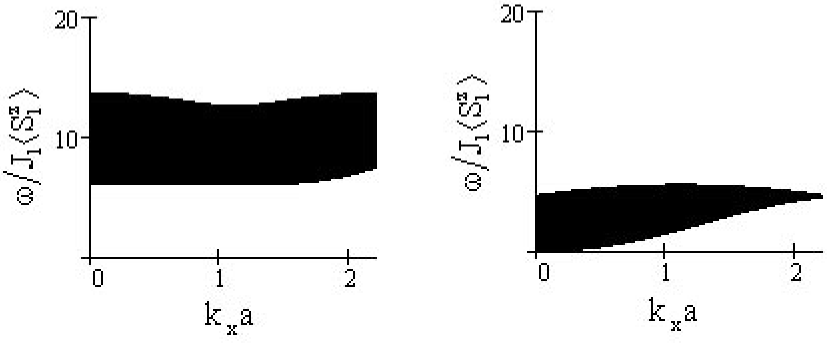

Fig. 3 Bulk spin–wave regions for superlattice, when $J/J_1 = 1.5$ and the other parameters are chosen as Fig. 1.

In Fig.2, 3 the results numerically illustrated for particular choice of parameters. Fig. 3 shows the bulk spin-wave regions for the superlattice as a function of the quantity $k_x a$, while fig. 2 shows those for the components 2 and 3. The analysis of the results shows that the width of the bulk-spin wave regions in ferromagnetic superlattice is depended on wave vectors and exchange interaction.

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FERROMAGNİT İFRAT QƏFƏSDƏ (110) MÜSTƏVİSİNƏ PERPENDİKULYAR İSTİQAMƏTDƏ YAYILAN HƏCM SPİN DALĞALARI

İki müxtəlif sadə kubik Heyzenberq ferromaqnitin atom laylarının növbələşməsindən alınan ifrat qəfəs tədqiq olunub. Qrin funksiyası metodu ilə ifrat qəfəsin oxu boyunca yayılan həcm spin dalğaları üçün dispersiya tənliyi tapılıb. Alınan nəticələr parametrlərin seçilmiş qiymətləri üçün kəmiyyətcə təsvir olunub.

В.А . Танрывердиев, В.С. Тагиев, С.М. Сеид-Рзаева

ОБЪЕМНЫЕ СПИНОВЫЕ ВОЛНЫ, РАСПРОСТРАНЯЮЩИЕСЯ В НАПРАВЛЕНИИ ПЕРПЕНДИКУЛЯРНОМ К ПЛОСКОСТИ (110) В ФЕРРОМАГНИТНОЙ СВЕРХРЕШЕТКЕ

Рассматривается сверхрешетка, состоящая из чередующихся слоев двух различных типов Гейзенберговских ферромагнетиков. Используя метод функции Грина получены дисперсионные уравнения для объемных спиновых волн, распространяющихся в направлении перпендикулярном к плоскости (110). Численные результаты представлены графически.

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