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BULK SPIN-WAVES PROPAGATION IN THE DIRECTION PERPENDICULAR TO THE (110) PLANE FOR AN ANTIFERROMAGNETIC SUPERLATTICE

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The theoretical studies of SL formed from alternating layers of simple-cubic Heisenberg antiferromagnetic materials have been presented. Using Green function method the dispersion equations of bulk spin waves propagation in direction perpendicular to the plane (110) have been derived for this systems. The numerical results have been shown graphically.

The enormous progress in preparation techniques for ultrathin films has a tremendous impact on the development of surface physics and of practical applications [1-3]. With the advance epitaxial growth technique, it is possible to grow very thin films of a few monolayer [4, 5]. Magnetic multilayers have applications in information technology. For example, discovery of the GMR effect [6-8] (for which Fert and Grunberg shared the 2007 Nobel Prize in Physics) impacted on computer read-head technology. Therefore, properties of magnetic superlattices (SLs) are of particular importance, both from the experimental and from the theoretical point of view [9,10]. Compared to bulk systems, these systems show novel magnetic and electronic features. The study of spin waves is very useful in determining the fundamental parameters that characterize magnetic SL. In magnetic SLs, elementary excitations have properties distinctly different from the modes associated with any one constituent [11,12]. Bulk spin waves of periodic structure or magnetic SLs have been analyzed theoretically in many special cases [10,12].

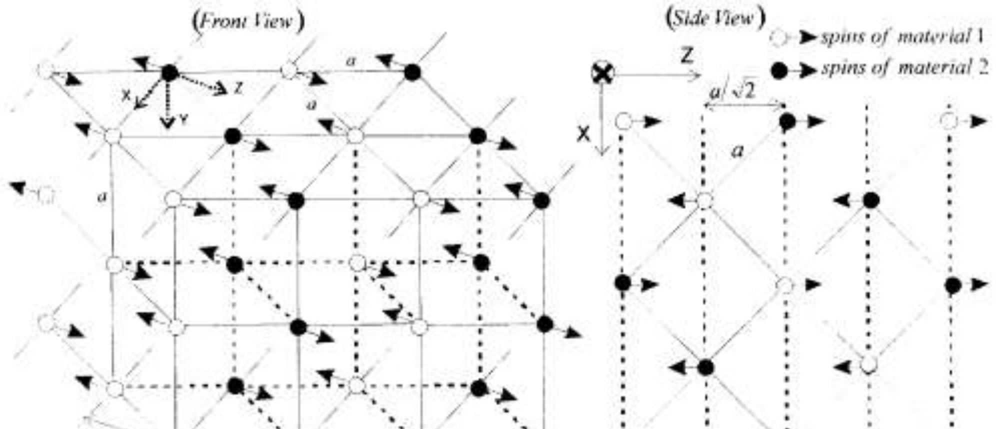

Fig.1.
A simple cubic antiferromagnetic SL model in which the atomic planes of material 1 alternate with atomic planes of material 2. The same lattice parameter a has been assumed for all materials.

The aim of this paper is to study by the Green function method [13] properties of an antiferromagnetic SL with quantum Heisenberg spins at finite temperature and this theoretical studies are analogous to one from [14], where bulk spin waves propagation in direction perpendicular to the plane (001) in ferromagnetic SL is considered. We consider a simple cubic antiferromagnetic SL model in which the atomic planes of material 1 alternate with atomic planes of material 2. Each atomic plane is assumed to be the [001] planes (Fig.1). The exchange interaction between atoms of the two atomic layers at each interface is assumed to be antiferromagnetic but different from the corresponding bulk couplings.

The Heisenberg Hamiltonian is used to describe for system

$$H = \sum_{i,j} J_{ij}\left(S_i S_j\right) - \sum_i g_i \mu_B \left(H_0 + H_i^{(A)}\right) S_{i,a}^z - \sum_i g_i \mu_B \left(H_0 - H_i^{(A)}\right) S_{i,b}^z \,, \qquad (1)$$

where H_0 is the internal field, which is assumed to be parale1l to the spins along the z axis and $H_i^{(A)}$ $(i = 1,2)$ anisotropy field for a antiferromagnet with simple unaxial anisotropy along the z axis. We define a double – time Green function in real space $\langle\langle S_i^+(t); S_j^-(t')\rangle\rangle$. By magnetic symmetry, there are two sublattices corresponding to up and down spins for both the materials. Writing the equation of motion for Green function and employing the random-phase approximation one obtains a set of equations coupling four different types of Green function, namely two of type $G_{i,j}(t,t') = \langle\langle S_{ia}^+(t); S_{ja}^-(t')\rangle\rangle$ where i and j belong to the same sublattice, and two of the type $F_{i,j}(t,t') = \langle\langle S_{ib}^+(t); S_{ja}^-(t')\rangle\rangle$ where i and j belong to different sublattices. Furthermore, to emphasize the layered structure we shal1 use the following the frequency and two-dimensional Fourier transformation [14]

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

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. Assuming that n-th layer is of the material 1 and $(n+1)$-th layer is of the material 2, one obtains the following set of equations when the exchange interaction between constituents is antiferromagnetically

$$\begin{cases} (\omega - \omega_H - \lambda_1) G_{n,n'}^{(1)} + \langle S_{1,a}^z\rangle \left\{2J_1 \cos k_y a F_{n,n'}^{(1)} + J_1 t F_{n+1,n'}^{(1)} + Jt F_{n-1,n'}^{(2)} + J_1 t^* F_{n-1,n'}^{(1)} + Jt^* F_{n+1,n'}^{(2)}\right\} = 2\langle S_{1,a}^z\rangle \delta_{n,n'} \\ (\omega - \omega_H + \lambda_1) F_{n,n'}^{(1)} + \langle S_{1,b}^z\rangle \left\{2J_1 \cos k_y a G_{n,n'}^{(1)} + J_1 t G_{n+1,n'}^{(1)} + Jt G_{n-1,n'}^{(2)} + J_1 t^* G_{n-1,n'}^{(1)} + Jt^* G_{n+1,n'}^{(2)}\right\} = 0 \\ (\omega - \omega_H - \lambda_2) G_{n,n'}^{(2)} + \langle S_{2,a}^z\rangle \left\{2J_2 \cos k_y a F_{n,n'}^{(2)} + J_2 t F_{n+1,n'}^{(2)} + Jt F_{n-1,n'}^{(1)} + J_2 t^* F_{n-1,n'}^{(2)} + Jt^* F_{n+1,n'}^{(1)}\right\} = 2\langle S_{2,a}^z\rangle \delta_{n,n'} \\ (\omega - \omega_H + \lambda_2) F_{n,n'}^{(2)} + \langle S_{2,b}^z\rangle \left\{2J_2 \cos k_y a G_{n,n'}^{(2)} + J_2 t G_{n+1,n'}^{(2)} + Jt G_{n-1,n'}^{(1)} + J_2 t^* G_{n-1,n'}^{(2)} + Jt^* G_{n+1,n'}^{(1)}\right\} = 0 \end{cases} \qquad (3)$$

where

$$\omega_H = g\mu_B H, \quad \lambda_{1(2)} = g\mu_B H_{1(2)}^{(A)} + 4J_{1(2)}\langle S_{1(2)}^z\rangle + 2J\langle S_{2(1)}^z\rangle, \ \mathrm{t} = \exp\left(\mathrm{i}k_x \mathrm{a}/\sqrt{2}\right), \ \mathrm{t}^* = \exp\left(-\mathrm{i}k_x \mathrm{a}/\sqrt{2}\right).$$

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

$$G_{n+1,n'}^{(1),(2)} = \exp\left(ik_z a/\sqrt{2}\right) G_{n,n'}^{(1),(2)}, \qquad F_{n+1,n'}^{(1),(2)} = \exp\left(ik_z a/\sqrt{2}\right) F_{n,n'}^{(1),(2)}. \qquad (4)$$

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

$$\begin{pmatrix} \omega - \lambda_1^a & J_1\langle S_1^z\rangle\alpha & 0 & J\langle S_1^z\rangle\beta \\ -J_1\langle S_1^z\rangle\alpha & \omega - \lambda_1^b & -J\langle S_1^z\rangle\beta & 0 \\ 0 & J\langle S_2^z\rangle\beta & \omega - \lambda_2^a & J_2\langle S_2^z\rangle\alpha \\ -J\langle S_2^z\rangle\beta & 0 & -J_2\langle S_2^z\rangle\alpha & \omega - \lambda_2^b \end{pmatrix} \begin{pmatrix} G_{n,n'}^{(1)} \\ F_{n,n'}^{(1)} \\ G_{n,n'}^{(2)} \\ F_{n,n'}^{(2)} \end{pmatrix} = \begin{pmatrix} 2\langle S_{1,a}^z\rangle\delta_{n,n'} \\ 0 \\ 2\langle S_{2,a}^z\rangle\delta_{n,n'} \\ 0 \end{pmatrix} \qquad (5)$$

where $\alpha = 2\cos k_y a + 2\cos\left(a(k_x + k_z)/\sqrt{2}\right)$, $\quad \beta = 2\cos\left(a(k_x - k_z)/\sqrt{2}\right)$.

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

$$\begin{aligned}&(\omega-\omega_H)^4+(\omega-\omega_H)^2\left\{J_1^2\langle S_1^z\rangle^2\alpha^2+2J^2\langle S_1^z\rangle\langle S_2^z\rangle\beta^2+J_2^2\langle S_2^z\rangle^2\alpha^2-\lambda_1^2-\lambda_2^2\right\}+\\&+J^4\langle S_1^z\rangle^2\langle S_2^z\rangle^2\beta^4-2J^2J_1J_2\alpha^2\beta^2\langle S_1^z\rangle^2\langle S_2^z\rangle^2+J_1^2J_2^2\alpha^4\langle S_1^z\rangle^2\langle S_2^z\rangle^2-J_2^2\langle S_2^z\rangle^2\lambda_1^2\alpha^2-\\&-2J^2\beta^2\langle S_1^z\rangle\langle S_2^z\rangle\lambda_1\lambda_2-J_1^2\langle S_1^z\rangle^2\lambda_2^2\alpha^2+\lambda_1^2\lambda_2^2=0\end{aligned} \qquad (6)$$

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 antiferromagnetic constituents [15]. In Fig.3 the results numerically illustrated for particular choice of parameters. Fig.3 shows the dependences of spin-wave frequencies on the quantity $k_x a$ and the quantity $k_z a$ for the SL, while Fig.2 shows those for the components 1 and 2.

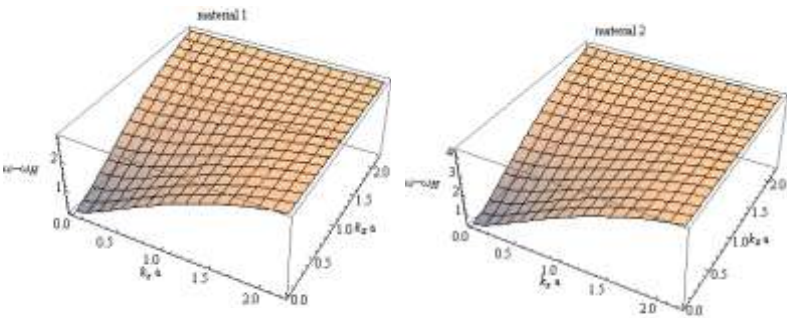

Fig.2.
The dependences of spin-wave frequencies on the quantity $k_x a$ and the quantity $k_z a$ for the the constituents 1 and constituents 2 with the parameters; $J_2/J_1=1.5$; $g_1=g_2$; $\langle S_1^z\rangle=\langle S_2^z\rangle$; $g_1\mu_B H_1^{(A)}/J_1\langle S_1^z\rangle=0.02$; $g_2\mu_B H_2^{(A)}/J_1\langle S_1^z\rangle=0.06$.

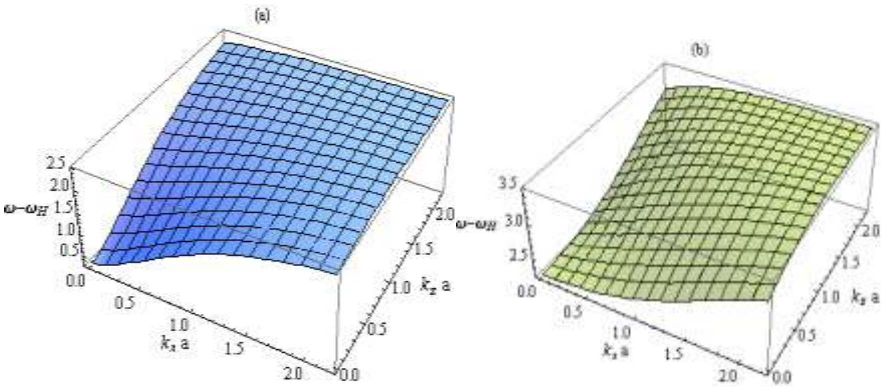

Fig.3.
The dependences of low-frequencies (a) and high-frequencies (b) on the quantity $k_x a$ and the quantity $k_z a$ for the SL with the parameters $J/J_1=0.5$; $J_2/J_1=1.5$; $g_1=g_2$; $\langle S_1^z\rangle=\langle S_2^z\rangle$; $g_1\mu_B H_1^{(A)}/J_1\langle S_1^z\rangle=0.02$; $g_2\mu_B H_2^{(A)}/J_1\langle S_1^z\rangle=0.06$.

The analysis of the results shows that there are two low and high- frequency excitations in the SL under consideration. The bulk-spin wave frequencies is depended on wave vectors and exchange interaction and the dispersion surfaces move up with increasing anisotropy field and exchange constants.

1. C.A.F.Vaz, J.A.C.Bland and G.Lauhoff, *Rep. Prog. Phys.*, **71** (2008) 056501.
2. T.K.Yamada, E.Martınez, A.Vega, R.Robles, D.Stoeffler, A.L.V´azquez de Parga, T.Mizoguchi, H.Van Kempen, *Nanotechnology*, **18** (2007) 235702.
3. A.Ernst, J.Henk and R.K.Thapa, *J. Phys.: Condens. Matter.*, **17** (2005) 3269.
4. A.Schreyer, T.Schmitte, R.Siebrecht, P.Bödeker. H.Zabel, S.H.Lee, R.Erwin, J.Kwo, M.Hong, C.F.Majkrzak, *J. Appl. Phys.*, **87** (2000) 5443.
5. J.Chen, G.Dresselhaus, M.S.Dresselhaus, G.Sprinhoulz, C.Picher, G.Bauer, *Phys. Rev.*, **B54** (1996) 4020.
6. M.N.Baibich, J.M.Broto, A.Fert, Van Dau F.Nguyen, F.Petroff, P.Etienne, G.Creuzet, A.Friederich, J.Chazelas, *Phys. Rev. Lett.*, **61** (1988) 2472.
7. G.Binasch, P.Grunberg, F.Saurenbach, W.Zinn, *Phys. Rev.*, **B 39** (1989) 4828.
8. P.Grunberg, et al., *J. Appl. Phys.*, **61** (1987) 3750.

9. P.Warnicke, G.Andersson, M.Bjorck, J.Ferre, P.Nordblad, *J. Phys.: Condens. Matter*, **19** (2007) 226218.
10. V.A.Tanriverdiyev, V.S.Tagiyev, S.M.Seyid-Rzayeva, P*hys. Stat. Sol., (b)* **240** (2003) 183.
11. S.Soriano, C.Dufour, K.Dumesnil, A.Stunault, *J. Phys.: Condens. Matter*, **18** (2006) 4127.
12. V.A.Tanriverdiyev, V.S.Tagiyev*, Superlatticies and Microstructures,* **43** (2008) 190.
13. [13] M.Y.Zhuravlev, J.D.Burton, A.V.Vedyayev, E.Y.Tsymbal*, J. Phys. A: Math. Gen.*, **38** (2005) 5547.
14. V.A.Tanriverdiyev, V.S.Tagiyev, M.B.Guseynov, *Transactions of Azerbaijan Academy of Sciences, Series of Physical-mathematical and Technical sciences, Physics and Astronomy*, **XX** №2 (2000) 45.
15. R.E.DeWames, T.Wolfram, *Phys. Rev*., **185** (1969) 720.

ANTIFERROMAQNIT IFRAT QƏFƏSDƏ (110) MÜSTƏVISINƏ PERPENDIKULYAR ISTIQAMƏTDƏ YAYILAN HƏCM SPIN DALĞALARI

V.Ə.TANRIVERDIYEV, V.S.TAĞIYEV

İki müxtəlif sadə kubik Heyzenberq antiferromaqnit atom laylarının növbələşməsindən alınan ifrat qəfəs tədqiq olunur. Qrin funksiyası metodu ilə (110) müstəvisinə perpendikulyar istiqamətdə yayılan həcm spin dalğası üçün dispersiya tənliyi tapılıb. Alınmış nəticələr kəmiyyətcə təsvir olunub.

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

В.А.ТАНРЫВЕРДИЕВ, В.С.ТАГИЕВ

Рассматривается сверхрешетка, состоящая из чередующихся слоев двух различных типов Гейзенберговских антиферромагнетиков. Используя метод функции Грина, получили дисперсионные уравнения для объемных спиновых волн, распространяющихся в направлении перпендикулярном к плоскости (110). Полученные результаты численно интерпретированы.

Редактор:Р.Гусейнов