SURFACE SPIN WAVES IN A SEMI INFINITE FERROMAGNETIC SUPERLATTICE

V.A. TANRIVERDIYEV, V.S. TAGIYEV, S.M. SEYID-RZAYEVA
Institute of Physics of Academy of Sciences of Azerbaijan
3700143, Baku, H. Javid, av. 33

A semi-infinite superlattice consisting of alternating layers of two-simple Heizenberg ferromagnetics is considered. Using Green function method the dispersion equations of surface spin waves are derived for semi-infinite systems. The numerical results are shown graphically.

Surface acoustic and optical waves of periodic structure or magnetic superlattices have been analyzed theoretically in many special cases [1,2]. In the short-wavelength limit, where the exchange coupling is daminant, comparatively fewer studies have been done. A surface spin wave is an eigenstate, in the spin-wave approximation (magnon-magnon interactions are neglected) of a finite or semi-finite crystal for which the amplitude of spin excitation is localized principally at or near the surface. The bulk spin wave has constant phase a spatially varying amplitude. For optical surface spin-wave the spins on adjacent layers are 180° out of phase and the amplitude decreases with increasing distance into the crystal.

In this paper, we study a simple cubic ferromagnetic semi-infinite superlattice model in which the atomic planes of material 1 alternate which atomic planes of material 2. Each atomic plane is assumed to be the [001] planes.

We consider here the following Heizenberg Hamiltonian:

$$H = -\frac{1}{2}\sum_{i,j} I_{ij}\left(S_i S_j\right) - \sum_i g\mu_B H_0 S_i^z \quad , \quad (1)$$

where I_{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.

From this Hamiltonian, assuming that surface layer is of the material $1\ (1=1,2)$ and the second layer is of the material $1'\ \left(1' \neq 1;\ 1' = 1,2\right)$ one obtains [3] the following set of equations:

$$\begin{cases} \left(E - A_s\right)g_{1,n} + \dfrac{\varepsilon}{6} g_{2,n} = 2S_1\delta_{1,n} , \\ \dfrac{\varepsilon}{6} g_{1,n} + \left(E - A_{1'}\right)g_{2,n} + \dfrac{\varepsilon}{6} g_{3,n} = 2S_2\delta_{2,n} , \\ \dfrac{\varepsilon}{6}\left(1 + \dfrac{1}{x}\right)g_{2,n} + \left(E - A_1\right)g_{3,n} = 2S_3\delta_{3,n} , \end{cases} \quad (2)$$

where $g=6I_1S<<S^+;S^->>$, $E=(w-g\mu_B H_0)/6I_1S$, $x=\exp(-idk_z)$

The set of equation (2) may be written under the following matrix form

$$\begin{vmatrix} \left(E - A_s\right) & \dfrac{\varepsilon}{6} & 0 \\ \dfrac{\varepsilon}{6} & E - A_{1'} & \dfrac{\varepsilon}{6} \\ 0 & \dfrac{\varepsilon}{6}\cdot\left(1 + \dfrac{1}{x}\right) & E - A_1 \end{vmatrix} \begin{vmatrix} g_{1,n} \\ g_{2,n} \\ g_{3,n} \end{vmatrix} = \begin{vmatrix} 2S_1\delta_{1,n} \\ 2S_2\delta_{2,n} \\ 2S_3\delta_{3,n} \end{vmatrix} \quad (3)$$

We also use the following equation [3].

$$\left(E - A_1\right)\left(E - A_2\right) - \left(\frac{\varepsilon}{6}\right)^2\left(1 + x\right)\left(1 + \frac{1}{x}\right) = 0 \quad (4)$$

The dispersion equations of surface waves are obtained using equation (3) and (4).

$$E = A_s + \frac{1}{x}\left(A_s - A_1\right) ,\ \left(1 = 1,2\right)$$
$$x = p \pm \sqrt{p^2 + Q}. \quad (5)$$

For the acoustic surface solutions $x>1$, $x<-1$ for the optical solutions and bulk solutions have $|x|=1$ [4]. We find that in the expression of x (5) plus sign for acoustic modes and minus sign for optical modes are taken, respectively. In general, the surface wave may be characterized by one or more complex decay constants, but the amplitude envelope decrease rapidly with increasing distance from the surface. In many instances, a surface wave branch may not exist for all values of q. In some cases surface acoustic and optical branches exist only for q greater than critical value q_c while in others q must be less than q_c. Such truncated branches are usually terminated at value of q for which degeneracy with the bulk continium occurs, i.e. $E_S(q_C) = E_B(q_C)$. One obtains the following expressions of critical value of q when assuming surface layer is of the material 1.

$$q_{1c}^{a} = \frac{\varepsilon(3+\alpha-4\varepsilon_s)}{4(1-\varepsilon_s)(2\varepsilon_s-\alpha-1)}, \qquad q_{1c}^{0} = \frac{\varepsilon}{4(\varepsilon_s-1)}, \tag{6}$$

and when assuming surface layer is of the material 2.

$$q_{2c}^{a} = \frac{\varepsilon(3\alpha+1-4\varepsilon_s)}{4(\alpha-\varepsilon_s)(2\varepsilon_s-\alpha-1)}, \qquad q_{2c}^{0} = \frac{\varepsilon}{4(\varepsilon_s-\alpha)}, \tag{7}$$

The number of surface waves as a function of ε_s are shown in fig.1 for a particular choice of parameters. The results show that all surface branches may disappear. For example, when surface layer is of the material 1 and $\alpha=2$, $\varepsilon=1.5$ and $\varepsilon_s=1.2$ acoustic waves appear in the range $0 \le q \le 0.625$, optical waves appear in the range $1.875 \le q \le 2$ and all surface waves disappear in the range $0.625 < q < 1.875$. We may also investigate the behavior of ferromagnetic superlattice when surface exchange constant is negative.

From fig.2, we can also see clearly how the surface and bulk waves change with q for different values of ε and ε_s. All optical branches are between two bulk bands. Both optical and acoustic branches move upward with increasing ε. Truncated or complete optical and acoustic branches occur for various values of ε and ε_s.

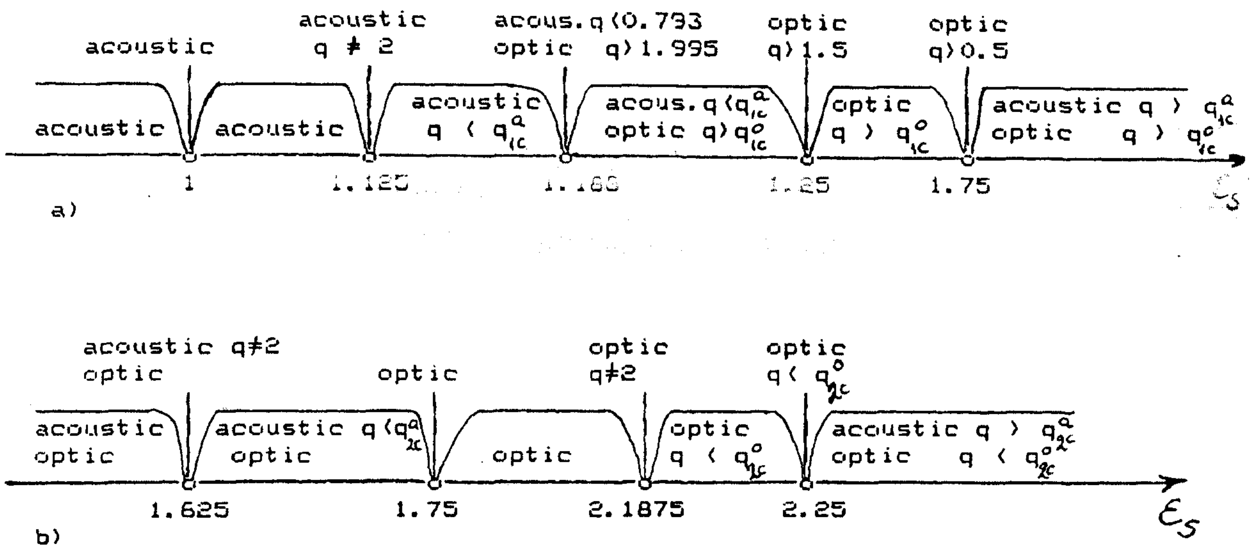

Fig.1. Number of surface waves as a function of ε_s. a) surface layer is of material 1, b) surface layer is of material 2: in both case $\alpha=2$; $\varepsilon=1.5$ and $0 \le q \le 2$.

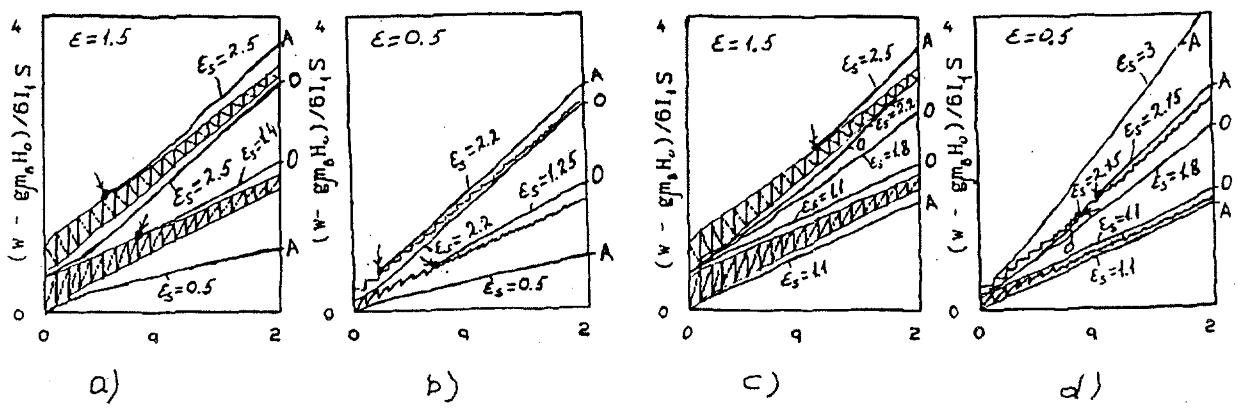

Fig.2. The surface and bulk waves in the superlattice as a function of q. A – acoustic; O –optical; the bulk bands are shown as shaded areas. a) and b) surface layer is of material 1 and $\alpha=2$: a) $\varepsilon=1.5$, $q_{1c}^{a}(2.5)=0.625$, $q_{1c}^{o}(1.4)=0.937$; b) $\varepsilon=0.5$, $q_{1c}^{a}(2.2)=0.282$ $q_{1c}^{o}(1.25)=0.5$; c) and d) surface layer is of material 2 and $\alpha=2$: c) $\varepsilon=1.5$, $q_{2c}^{a}(2.5)=1.125$, $q_{2c}^{o}(2.2)=1.875$; d) $\varepsilon=0.5$, $q_{2c}^{a}(2.15)=1.026$, $q_{2c}^{a}(3)=0.208$, $q_{2c}^{o}(2.15)=0.833$.

APPENDIX:

The terms appearing in the equations (1-7) are

$$A_s = \frac{\varepsilon}{6} + \frac{2}{3}\varepsilon_s q \ , \ q = 1 - \frac{1}{2}\left(\cos k_x a + \cos k_y a\right)$$

$$A_1 = \frac{\varepsilon}{3} + \frac{2}{3}\varepsilon q \ , \ \varepsilon_s = \frac{J_s}{J_1} \ , \ \varepsilon = \frac{J}{J_1} \ ; \ \alpha = \frac{J_2}{J_1}$$

$$A_2 = \frac{\varepsilon}{3} + \frac{2}{3}\alpha q \ ,$$

$$P = \frac{8}{\varepsilon^2}(1 - \varepsilon_s)(\alpha - \varepsilon_s)q^2 + \frac{2}{\varepsilon}q(1 + \alpha - 2\varepsilon_s) \ ,$$

$$Q = \frac{36(A_3 - A_1)^2}{\varepsilon^2} \qquad (1 = 1,2)$$

---

[1] *Feng Chen and H.K .Sy* .J. Phys.: Condens., Matter., 1995, 7.

[2] *R.E. DeWames and T. Wolfram.* Phys. Rev., 1969, 185, 752.

[3] *V.S. Tagiyev, V.A. Tanriverdiyev, S.M. Seyid-Rzayeva, M.B. Guseynov.* Fizika, 2000, 6, №1, p. 33.

[4] *Sydney G.Davison.* «Progress in surface science», v.2, part 4.

V.Ə. Tanrıverdiyev, V.S. Tağıyev, S.M. Seyid-Rzayeva

YARIMMƏHDUD FERROMAQNİT İFRAT QƏFƏSDƏ SƏTH SPİN DALĞALARI

İki sadə kubik Heyzenberg ferromaqnitdən təşkil olunmuş yarımməhdud ifrat qəfəsə baxılır. Qrin funksiyası metodundan istifadə edərək yarım məhdud ifrat qəfəs üçün səth spin dalğalarının dispersiya tənliyi müəyyən edilmişdir. Nəticə qrafik təsvir olunmuşdur.

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

ПОВЕРХНОСТНЫЕ СПИНОВЫЕ ВОЛНЫ В ПОЛУОГРАНИЧЕННЫХ ФЕРРОМАГНИТНЫХ СВЕРХРЕШЕТКАХ

Рассмотрена полуограниченная сверхрешетка, состоящая из двух типов простых кубических Гейзенберговских ферромагнетиков. Методом функции Грина найдены дисперсионные уравнения, описывающие распространение поверхностных спиновых волн в полуограниченных сверхрешетках. Результаты представлены графически.

Дата поступления: 07.09.00 *Редактор: Ф.М. Гашимзаде*