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Effect of anisotropy on the magnon energy gap in a two-layer ferromagnetic superlattice

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ABSTRACT

The magnon energy bands or spectra in a two-layer ferromagnetic superlattice are studied. It is found that a modulated energy gap exists in the magnon energy band along K_x direction perpendicular to the superlattice plane, which is different from the optical magnon gap at $K_x = 0$. The anisotropy, the spin quantum numbers and the interlayer exchange couplings all affect the magnon energy gap. If the anisotropy exists, there will be no acoustic energy branch in the system. There is a competition effect of the anisotropy and the spin quantum number on the magnon energy gap. The competition achieves a balance at the zero energy gap, at which the symmetry of the system is higher. The two energy spectra of the two-layer ferromagnetic superlattice are lowered with increasing temperature.

1. Introduction

Investigation of layered magnetic systems has been a subject of growing interests in condensed matter physics [1–3], because the characteristics of artificial multilayer/superlattice materials are quite different from those of their bulk component materials [4–6]. The magnetic anisotropy is an important parameter in superlattice systems [7–9], which may dominate other physical properties, such as the spin–wave excitation spectrum or the magnetization, of a magnetic system. For multilayered magnetic materials, either the addition of a single layer to a film or the variety of structural (or magnetic) parameters (for instance, anisotropy, spin quantum numbers, interlayer and intralayer exchange couplings) of a material would load to new features in the energy band and the magnetic properties of the material.

The materials with periodic magnetic structure can be refereed to magnonic crystals. In magnetic superlattices, the magnon as a kind of spin excitations is an interesting subject [10–25]. LePage and Camley investigated the spin–wave spectrum of a superlattice consisting of two alternating ferromagnetic films with antiferromagnetic coupling at interfaces [13]. A theory was presented for bulk and surface spin waves in a triangular antiferromagnet with ferromagnetic interlayer coupling, and developed for spin–wave dispersions of a semi-infinite frustrated system and also thin films [14]. Interface spin waves (ISW) in a bilayer of two-sublattice Heisenberg ferrimagnet with the nearest-neighboring exchange interaction were investigated [15]. The spin–wave spectrum and the ferromagnetic resonance spectra of a magnetic thin film were studied by van Stapele et al. [16]. Temperature dependence of magnetization and optical magnon gap in antiferromagnetic $YBa_2Cu_3O_6$ bilayer was obtained by employing the Green's function technique and the Callen decoupling approximation [17]. Barnas [18] analyzed the spin–wave spectrum of infinite, semi-infinite, and finite ferromagnetic superlattices with arbitrary elementary units by the transfer-matrix formalism. The spin–wave spectra of three- and four-layer superlattices (and the corresponding sublattices) were studied analytically, by using the bosonization Holstein–Primakoff transformation in the linear spin–wave approximation and the Bogoliubov transformation [19,26]. It was found that the magnon energy gap strongly affects physical properties of layered magnetic system [20].

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However, little attention has been paid on a systemically theoretical study of the magnon energy gap of superlattices. Deng et al. [21] studied the magnon energy gap of an anisotropic two-layer superlattice by using local coordinates and a spin-Bose transformation quantum approach. The magnon dispersion with two ferromagnetic layers was calculated in the pure exchange limit, the pure dipolar limit, and both the exchange and dipolar interactions. It was presented that the magnon energy gap derives mainly from the exchange interaction [22,23]. In our previous work [24,25], the magnon energy band was studied for ferrimagnetic [24] and ferromagnetic [25] superlattices with three layers in a unit cell. The results showed that there are two modulated energy gaps, and the absence of the energy gap means that the system has a high magnetically structural symmetry [24,25].

In order to understand further the magnon energy gap of superlattices, in this report, we study the effect of a single-ion anisotropy on the magnon energy gap in a superlattice constructed by two kinds of ferromagnetic materials that are ferromagnetically coupled. It is observed that, there are two energy spectra branches along K_x direction in this two-layer ferromagnetic superlattice. The energy gap can exist in the magnon energy band of the system. The anisotropy, the spin quantum numbers and the interlayer exchange couplings all affect the magnon energy gap. If the anisotropy exists, there will be no acoustic energy branch in the system. We find a competition effect of the anisotropy and the spin quantum number on the magnon energy gap $\Delta\omega_{12}$. The competition achieves a balance at the zero energy gap, at which the symmetry of the system is higher. The two energy spectra of the two-layer ferromagnetic superlattice are lowered with increasing temperature.

The outline of this paper is as follows: In Section 2, we describe the model, Hamiltonian of the system and calculation procedure. Section 3 represents the effect of anisotropy, spin quantum numbers and interlayer exchange couplings on the energy gap. Section 4 gives a conclusion.

2. Model and calculation procedure

We consider a Heisenberg model with a single-ion anisotropy for a two-layer ferromagnetic superlattice on a simple cubic lattice. A schematic model of a two-layer superlattice was illustrated in Fig. 1. A unit cell of the superlattice consists of two layers, 1 and 2, where spins are denoted by S_l ($l = 1, 2$) for each layer. The nearest neighboring spins within each sublayer are coupled ferromagnetically by intralayer exchange couplings J_l ($l = 1, 2$), respectively. The interlayer exchange couplings J_{12} between spins at the nearest neighboring layers are ferromagnetic. The superlattice structure is stacked periodically along x-direction that is normal to layers (yz-planes). The Hamiltonian is

$$H = -\frac{1}{2}\sum_{l=1}^{2}\sum_{\rho,\delta_{//}} J_l S_{l,\rho} S_{l,\rho+\delta_{//}} - \sum_{l=1}^{2}\sum_{\rho} J_{12} S_{l,\rho} S_{l+1,\rho} - \sum_{l=1}^{2}\sum_{\rho} D_l (S^Z_{l,\rho})^2 \tag{1}$$

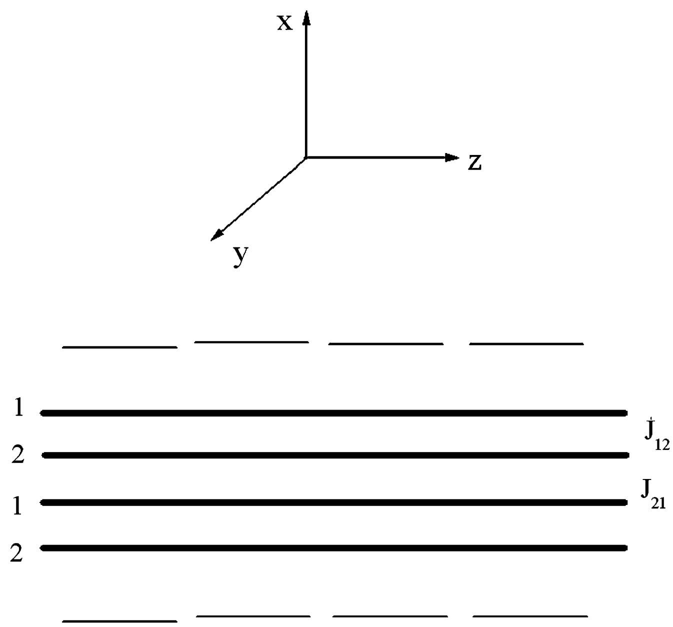

Fig. 1. A schematic model of the two-layer ferromagnetic superlattice, where only the interlayer exchange couplings are illustrated.

$$D(\omega) = \begin{vmatrix} \omega - (4J_1\langle S_1^z\rangle(1-\gamma_{k_{//}}) + 2J_{12}\langle S_2^z\rangle + 2D_1\langle S_1^z\rangle) & 2J_{12}\langle S_1^z\rangle\gamma_{k_\perp} \\ 2J_{12}\langle S_2^z\rangle\gamma_{k_\perp} & \omega - (4J_2\langle S_2^z\rangle(1-\gamma_{k_{//}}) + 2J_{12}\langle S_1^z\rangle + 2D_2\langle S_2^z\rangle) \end{vmatrix} \tag{6}$$

where l is the number of sublayers, $\delta_{//}$ represents that only the exchanges between the nearest neighbors in yz-planes are taken into account. The direction of spins of the initial state in the two sublayers is along the positive z-direction. Therefore, the interlayer exchange couplings J_{12} and the intralayer ones J_1 and J_2 are positive. The anisotropy constants are denoted by D_l ($l = 1,2$) for each layer. There are N sites on each layer-lattice, and total $2N$ sites for the system. To analyze the two-layer ferromagnetic superlattice, we introduce the Green functions, according to Callen [27]:

$$G_1(\omega, i_1, i_2) = \langle\langle S^+_{i_1} | \exp(pS^z_{i_2}) S^-_{i_2}\rangle\rangle_\omega \tag{2a}$$

$$F_1(\omega, j_2, i_2) = \langle\langle S^+_{j_2} | \exp(pS^z_{i_2}) S^-_{i_2}\rangle\rangle_\omega \tag{2b}$$

$$G_2(\omega, j_1, j_2) = \langle\langle S^+_{j_1} | \exp(qS^z_{j_2}) S^-_{j_2}\rangle\rangle_\omega \tag{3a}$$

$$F_2(\omega, i_2, j_2) = \langle\langle S^+_{i_2} | \exp(qS^z_{j_2}) S^-_{j_2}\rangle\rangle_\omega \tag{3b}$$

where p and q are parameters. Using the technique of the equation of motion for the Green functions, within the Tyablikov decoupling approximation, we obtain the Fourier components of the Green functions:

$$\begin{pmatrix} G_1(\omega,k) & F_2(\omega,k) \\ F_1(\omega,k) & G_2(\omega,k) \end{pmatrix} = \frac{1}{D(\omega)} \begin{pmatrix} F_1(p) & 0 \\ 0 & F_2(q) \end{pmatrix} \begin{pmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{pmatrix} \tag{4}$$

where

$$F_1(p) = \langle [S_i^+, \exp(pS_i^z) S_i^-] \rangle \tag{5a}$$

$$F_2(q) = \langle [S_j^+, \exp(qS_j^z) S_j^-] \rangle \tag{5b}$$

where ω represents the energy spectrum of the system, $\langle S_1^z\rangle$ and $\langle S_2^z\rangle$ are sublayer magnetizations per site (the unit is taken to be

$g\mu_B$) in sublayers 1 and 2, respectively. Here

$$\gamma_{k_{//}} = \frac{1}{4}\sum_{\delta_{//}} e^{ik\cdot\delta_{//}} \tag{7a}$$

$$\gamma_{k_{\perp}} = \frac{1}{2}\sum_{\delta_{\perp}} e^{ik\cdot\delta_{\perp}} \tag{7b}$$

The parameters M_{ij} ($i, j = 1,2$) in Eq. (4) are given as follows:

$$\begin{aligned}
M_{11} &= \omega - (4J_2\langle S_2^z\rangle(1-\gamma_{k_{//}}) + 2J_{12}\langle S_1^z\rangle + 2D_2\langle S_2^z\rangle)\\
M_{12} &= -2J_{12}\langle S_2^z\rangle\gamma_{k_{\perp}}\\
M_{21} &= -2J_{12}\langle S_1^z\rangle\gamma_{k_{\perp}}\\
M_{22} &= \omega - (4J_1\langle S_1^z\rangle(1-\gamma_{k_{//}}) + 2J_{12}\langle S_2^z\rangle + 2D_1\langle S_1^z\rangle)
\end{aligned} \tag{8}$$

After using the spectral theorem and Callen's [27] technique, we finally obtain the magnetization of each sublayer as

$$\langle S_1^z\rangle = \frac{(S_1+1+n_1)n_1^{2S_1+1} + (S_1-n_1)(1+n_1)^{2S_1+1}}{(1+n_1)^{2S_1+1} - n_1^{2S_1+1}} \tag{9a}$$

$$\langle S_2^z\rangle = \frac{(S_2+1+n_2)n_2^{2S_2+1} + (S_2-n_2)(1+n_2)^{2S_2+1}}{(1+n_2)^{2S_2+1} - n_2^{2S_2+1}} \tag{9b}$$

where n_1 and n_2 are the auxiliary functions:

$$n_1 = \frac{1}{N}\sum_k\sum_{i=1}^{2}\frac{M_{11}(\omega_i)}{(e^{\beta\omega_i}-1)\prod_{m\neq i}(\omega_i-\omega_m)} \tag{10a}$$

$$n_2 = \frac{1}{N}\sum_k\sum_{i=1}^{2}\frac{M_{22}(\omega_i)}{(e^{\beta\omega_i}-1)\prod_{m\neq i}(\omega_i-\omega_m)} \tag{10b}$$

Here $\beta = 1/k_BT$, T is temperature of the system. Setting the determinant to zero:

$$D(\omega) = 0 \tag{11}$$

Carrying out numerical calculation to solve self-consistently the fundamental Eqs. (9)–(11), we obtain two positive solutions for the spin–wave spectra of the ferromagnetic two-layer superlattice.

In the following, we shall discuss whether the energy gaps exist in the energy band structure along the K_x direction (perpendicular to the superlattice plane), and how the spin quantum number, the interlayer exchange couplings, the anisotropy constants and the temperature affect these energy gap or energy spectra.

3. Results and discussion

Fig. 2 shows the K_x dependence of the energy spectra of the two-layer ferromagnetic superlattices. Two energy spectra branches ω_1 and ω_2 exist in the system: ω_1 is an acoustic branch and ω_2 is optical. There is a magnon energy gap $\Delta\omega_{12}$. The magnon energy gap $\Delta\omega_{12}$ is defined as the gap between the top of the branch ω_1 and the bottom of the branch ω_2, which is different from the optical magnon gap at $K_x = 0$. As the cases of photon, electron and phonon, the magnon energy gap should affect strongly physical properties of the magnetic system.

First, we discuss the effect of the spin quantum number and the interlayer exchange couplings on the magnon energy gap of the two-layer ferromagnetic superlattice. Fig. 3(a) represents the dependence of the magnon energy gap $\Delta\omega_{12}$ on the first- and the second-layer spin quantum numbers S_1 and S_2, as $J_{12} = 1.0$, $J_1 = J_2 = 1.0$, and $D_1 = D_2 = 0$. From Fig. 3(a), the spin quantum numbers S_1 and S_2 have the same contribution to the energy gap $\Delta\omega_{12}$ that approaches to zero only when S_1 approaches to S_2.

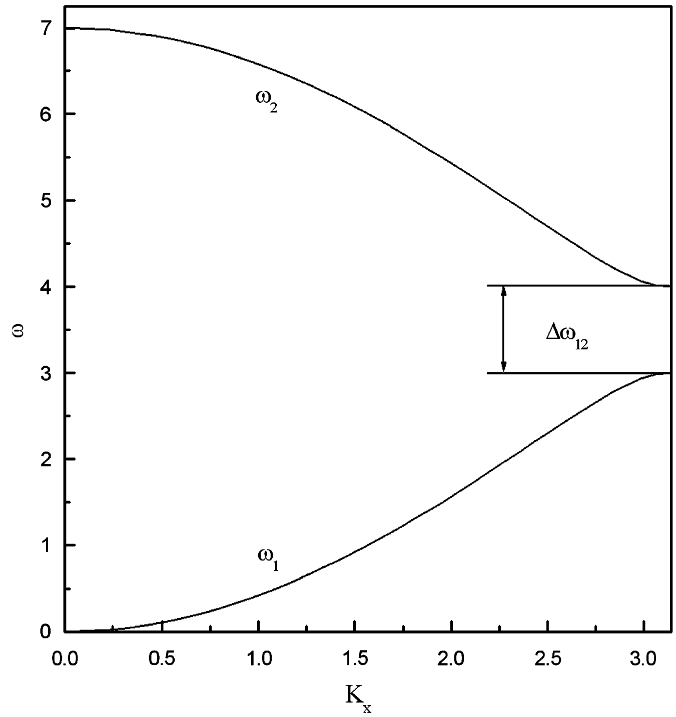

Fig. 2. K_x dependence of the energy spectra ω of the two-layer ferromagnetic superlattices with $S_1 = 2.0$, $S_2 = 1.5$, $J_1 = J_2 = 1.0$, $J_{12} = 1.0$, $D_1 = D_2 = 0.0$, $K_y = K_z = 0$ and t ($= k_BT$) $= 0$. Here, $\Delta\omega_{12}$ is the energy gap between the energy spectra ω_1 and ω_2.

The energy gap $\Delta\omega_{12}$ increases with increasing the difference of S_1 and S_2.

Fig. 3(b) shows the dependence of the energy gap $\Delta\omega_{12}$ on the spin quantum number S_1 and the interlayer coupling J_{12}. Here parameters for calculations are: $S_2 = 1.0$, $D_1 = D_2 = 0$, and $J_1 = J_2 = 1.0$. It is seen from Fig. 3(b) that, the energy gap $\Delta\omega_{12}$ approaches to zero only when S_1 is close to S_2, which is consistent with Fig. 3(a). J_{12} dose not affect the zero energy gap, but it affects the non-zero energy gap. For the non-zero energy gap, the energy gap $\Delta\omega_{12}$ increases with increasing J_{12}. The spin quantum number S_1 and the interlayer exchange coupling J_{12} all affect the energy gap $\Delta\omega_{12}$.

The effects of the anisotropy constants D_1 and D_2 on the energy gap are shown in Figs. 4–7. When the anisotropy exists in the system, the acoustic energy branch does not exist. From Fig. 4, if $D_1 = D_2 = 0.2$ the acoustic energy branch does not exist, and there is a magnon excitation gap at $K_x = 0$. However, such magnon excitation gap is different from the optical magnon gap at $K_x = 0$. By numerical calculation, one knows that, the effects of the anisotropy constants D_1 and D_2 on the energy gap are similar to those of the spin quantum numbers. Only when D_1 approaches to D_2, the energy gap $\Delta\omega_{12}$ approaches to zero as $S_1 = S_2$, and $J_1 = J_2$. The energy gap $\Delta\omega_{12}$ increases with increasing the difference of D_1 and D_2. Namely, the anisotropy also affect sensitively the energy gap $\Delta\omega_{12}$.

Fig. 5 represents the dependence of the energy gap $\Delta\omega_{12}$ on the spin quantum number S_1 and the anisotropy constant D_1 of the first layer. Here parameters for calculations are: $D_2 = 0.2$, $S_2 = 1.5$, $J_{12} = 1.0$ and $J_1 = J_2 = 1.0$. It is clear that, the energy gap $\Delta\omega_{12}$ surges. In the S_1–D_1 parametric region shown in Fig. 5, there are six points at which the energy gap $\Delta\omega_{12}$ vanishes, where $D_1 = 0.2$, $S_1 = 1.5$; $D_1 = 0.4$, $S_1 = 2.0$; $D_1 = 0.52$, $S_1 = 2.5$; $D_1 = 0.6$, $S_1 = 3.0$; $D_1 = 0.7$, $S_1 = 4.0$; $D_1 = 0.76$, $S_1 = 5.0$. For the first set of parameters D_1 and S_1, the system corresponds to the case discussed above, which is easy to be understood. However,

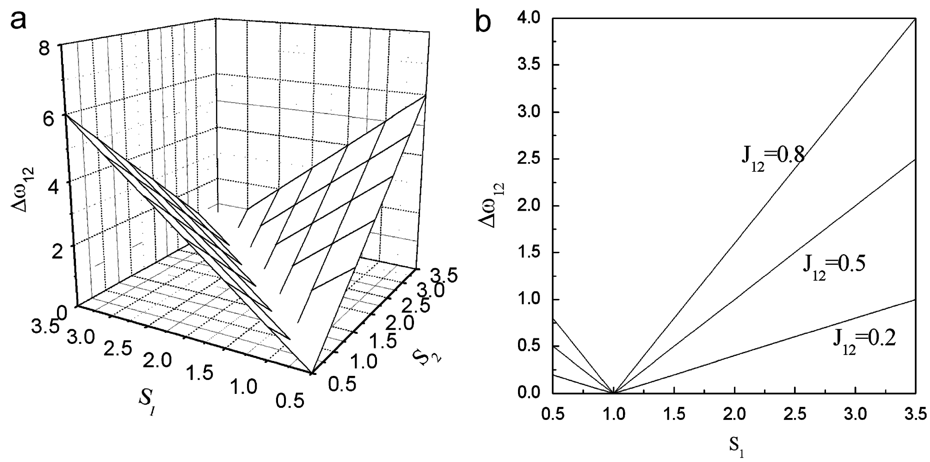

Fig. 3. (a) S_1 and S_2 dependence of the magnon energy gap $\Delta\omega_{12}$ of the two-layer ferromagnetic superlattices, with $J_{12}=1.0$, $D_1=D_2=0$, $J_1=J_2=1.0$, and $t\ (=k_BT)=0$ and (b) S_1 and J_{12} dependence of the magnon energy gaps $\Delta\omega_{12}$ of the two-layer ferromagnetic superlattices, with $S_2=1.0$, $D_1=D_2=0$, $J_1=J_2=1.0$, and $t\ (=k_BT)=0$.

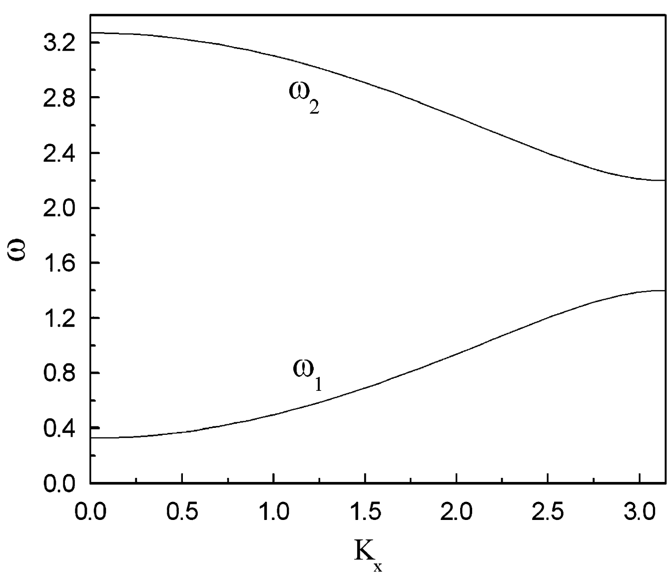

Fig. 4. K_x dependence of the energy spectra ω of the two-layer ferromagnetic superlattices with $S_1=1.0$, $S_2=0.5$, $J_1=J_2=1.0$, $J_{12}=1.0$, $D_1=D_2=0.2$, and $K_y=K_z=0$, and $t\ (=k_BT)=0$.

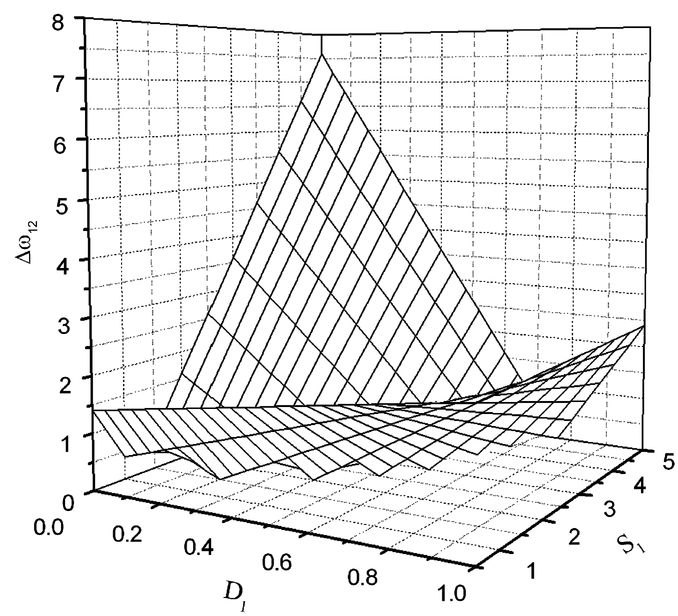

Fig. 5. D_1 and S_1 dependence of the magnon energy gap $\Delta\omega_{12}$ of the two-layer ferromagnetic superlattices, with $S_2=1.5$, $J_{12}=1.0$, $D_2=0.2$, $J_1=J_2=1.0$, and $t\ (=k_BT)=0$.

the system with other five sets of parameters does not correspond to that case, and S_1 increases with increasing D_1. We believe that this phenomenon is a new quantum effect, which can be understood by the competition effect of the anisotropy and the spin quantum number of the same layer on the magnon energy gap $\Delta\omega_{12}$.

Fig. 6 illustrates the dependence of the energy gap $\Delta\omega_{12}$ on the spin quantum number S_2 and the anisotropy constant D_1 of the first layer. Here parameters for calculations are: $D_2=0.2$, $S_1=1.5$, $J_{12}=1.0$, and $J_1=J_2=1.0$. From Fig. 6, the energy gap $\Delta\omega_{12}$ also surges in a region. But there is only one point with the zero energy gap $\Delta\omega_{12}$, where D_1 is close to 0.2 and S_2 close to 1.5. It is clear that at this point the system corresponds to the case discussed above. Moreover, there are two points with $D_1=0.465$, $S_2=1.0$; $D_1=0.735$, $S_2=0.5$, at which the energy gap $\Delta\omega_{12}$ is close to zero. From these three points, S_2 decreases with increasing D_1. It is due to the competition effect of the anisotropy and the spin quantum number of different layers on the magnon energy gap $\Delta\omega_{12}$.

In this system, there are effects of the magnetic anisotropy, which can be due to the interactions between the magnetic moments of atoms and the electric field of the crystal lattice. The single-ion anisotropy connects with the spin–orbit interaction, which is consistent with the overall symmetry of the crystal lattice [28]. Namely, the anisotropy energy consists of the factors of spin quantum number and anisotropy constant, related with the overall symmetry of the crystal lattice. Therefore, the zero energy gaps in Figs. 5 and 6 (except two points discussed above) are ascribed to the competition effect of the anisotropy constant and the spin quantum number on the magnon energy gap $\Delta\omega_{12}$. The competition achieves a balance at the zero energy gaps, at which the symmetry of the system is higher. This agrees with Refs. [21–25].

By numerical calculation, the effects of the anisotropy constants D_1 and J_{12} on the energy gap with $S_1=S_2$, $J_1=J_2$ are studied. It is shown that, the energy gap $\Delta\omega_{12}$ approaches zero only at a D_1 close to D_2. The energy gap $\Delta\omega_{12}$ increases with increasing the difference of D_1 and D_2. The interlayer exchange

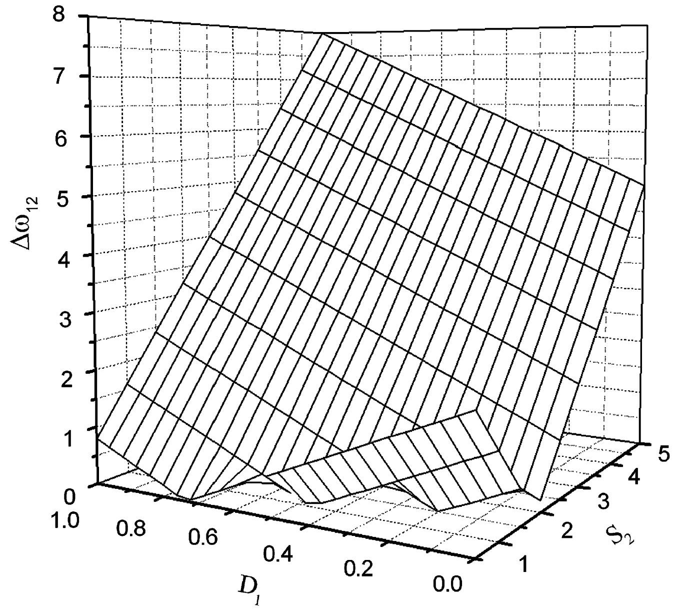

Fig. 6. D_1 and S_2 dependence of the magnon energy gap $\Delta\omega_{12}$ of the two-layer ferromagnetic superlattices, with $S_1=1.5$, $J_{12}=1.0$, $D_2=0.2$, $J_1=J_2=1.0$, and t $(=k_BT)=0$.

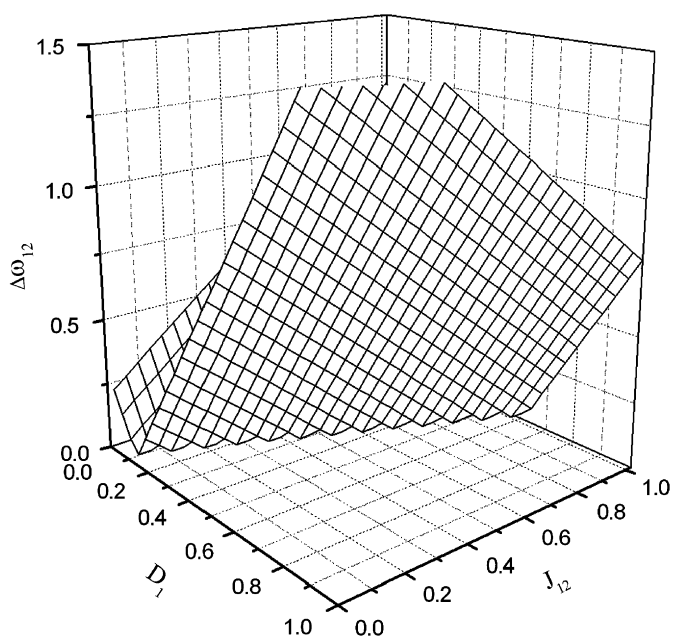

Fig. 7. D_1 and J_{12} dependence of the magnon energy gap $\Delta\omega_{12}$ of the two-layer ferromagnetic superlattices, with $S_1=1.0$, $S_2=0.5$, $D_2=0.2$, $J_1=J_2=1.0$, and t $(=k_BT)=0$.

coupling J_{12} affects neither the zero energy gap nor the non-zero energy gap. It is explained by that there is no competition effect between the anisotropy and the interlayer exchange coupling.

Fig. 7 represents the dependence of the magnon energy gap $\Delta\omega_{12}$ on the interlayer exchange couplings J_{12} and the anisotropy constant D_1 of the two-layer ferromagnetic superlattices, with $S_1=1.0$, $S_2=0.5$, $J_1=J_2=1.0$, and $D_2=0.2$. In Fig. 7, the interlayer exchange coupling J_{12} also affects the energy gap $\Delta\omega_{12}$. It is clear that there is a line with zero energy gap. In this system, there is the competition effect of the anisotropy constant and the spin quantum number on the magnon energy gap $\Delta\omega_{12}$,

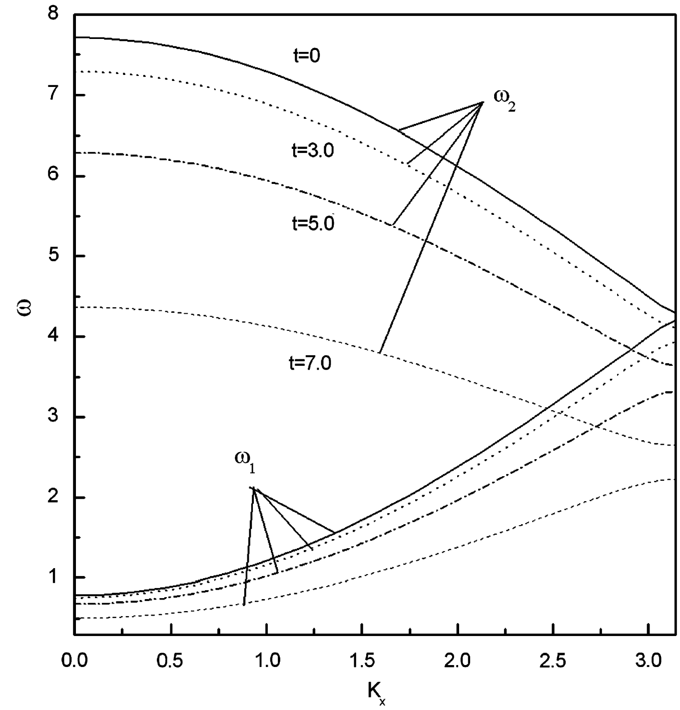

Fig. 8. K_x dependence of the energy spectra ω of the two-layer ferromagnetic superlattices with $S_1=2.0$, $S_2=1.5$, $J_1=J_2=1.0$, $J_{12}=1.0$, $D_1=0.3$, $D_2=0.1$, and $K_y=K_z=0$. Here, the solid, dotted, dash dotted and dashed curves represent the values of t $(=k_BT)=0$, 3.0, 5.0, and 7.0, respectively.

because of $S_1 \neq S_2$. The result in Fig. 7 can be understood by that the interlayer exchange coupling J_{12} affects the balance point of the competition between the spin quantum number and the anisotropy.

The effects of temperature t $(=k_BT)$ on the energy bands of the two-layer ferromagnetic superlattices with $S_1=2.0$, $S_2=1.5$, $J_1=J_2=1.0$, $J_{12}=1.0$, $D_1=0.3$ and $D_2=0.1$ are shown in Fig. 8. The two energy spectra ω_1 and ω_2 are lowered with increasing temperature t.

From discussion above, generally, the point at which $\Delta\omega_{12}$ is close to zero corresponds to that the spin quantum numbers (or the anisotropy constants) of two layers are close to equality. The energy gap $\Delta\omega_{12}$ increases with increasing the difference of S_1 and S_2 (or that of D_1 and D_2). From the dependence of the magnon energy gap $\Delta\omega_{12}$ on the anisotropy constant and the spin quantum number of the two-layer ferromagnetic superlattices, we have found a novel phenomenon: the value of the energy gap $\Delta\omega_{12}$ surges in a region, and several zero energy gaps exist. This is a quantum effect, which can be understood by the competition effect of the anisotropy and the spin quantum number on the magnon energy gap $\Delta\omega_{12}$.The competition achieves a balance at the zero energy gaps, at which the symmetry of the system is higher. Therefore, the zero magnon energy gap is related to high structural symmetry. Our point of view can be compared with that in literatures [21–25]. The magnon gap is a function of the magnetic anisotropy: the stronger the anisotropy is, the bigger the magnon gap is [21]. Schwenk et al. [22,23] also thought that the vanishing of gaps could be understood by a C_2 symmetry operation around the z-axis. In three-layer ferrimagnetic superlattice [24] and ferromagnetic one [25], two zero energy gaps correspond to different higher magnetically structural symmetry. The previous results [21–25] agree with the viewpoint of the present work. However, there is no competition effect between the anisotropy and the interlayer exchange coupling, but the interlayer exchange coupling affects the balance point of the competition of the spin quantum number and the anisotropy. And the two energy spectra ω_1 and ω_2 are lowered with increasing temperature.

Spin waves in the layered magnetic systems have been investigated by use of various classical and quantum theories. The classical approaches ignore quantum fluctuations that might significantly affect the magnon excitation. Here, we use the quantum double-time–temperature Green function method. The result is consistent with that of line spin wave at zero temperature. But the method is appropriate also to the region of high temperatures [27].

4. Conclusion

In conclusion, we have discussed the effects of the anisotropy, the spin quantum number, the interlayer exchange couplings and the temperature on the magnon energy band gap or spectra in the two-layer ferromagnetic superlattice, by means of a double-time–temperature spin Green's function. The main results are concluded as following.

There are two energy spectra branches along K_x direction in the two-layer ferromagnetic superlattice. In most cases, a magnon energy gap exists in the K_x direction in our system (except for when special conditions are satisfied, the energy gap vanishes). If the anisotropy exists $D_1 \neq 0$ (or $D_2 \neq 0$), the acoustic energy branch will not exist in the system, and there is a magnon excitation gap at $K_x = 0$. Such energy gap $\Delta\omega_{12}$ is different from the optical magnon gap normally at $K_x = 0$. The spin quantum numbers, the interlayer exchange couplings and the anisotropy all affect the magnon energy gap $\Delta\omega_{12}$. Generally, the point at which $\Delta\omega_{12}$ approaches to zero is near to the equality of the spin quantum numbers (or the anisotropy constants) of the two layers. The energy gap $\Delta\omega_{12}$ increases with increasing the difference of S_1 and S_2 (that of D_1 and D_2). From the dependence of the magnon energy gap $\Delta\omega_{12}$ on the anisotropy constant and spin quantum number, the value of the energy gap $\Delta\omega_{12}$ varies, and the zero energy gaps exist for several special cases. This new phenomenon can be understood by the competition effect of the anisotropy and the spin quantum number on the magnon energy gap $\Delta\omega_{12}$. The competition achieves a balance at the zero energy gaps, at which the symmetry of the system is higher. There is no competition effect between the anisotropy and the interlayer exchange coupling. The interlayer exchange coupling affects the balance point of the competition of the spin quantum number and the anisotropy. The two energy spectra of the two-layer ferromagnetic superlattice are lowered with increasing temperature.

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