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Single-magnon tunneling through a ferromagnetic nanochain

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Magnon transmission between ferromagnetic contacts coupled by a linear ferromagnetic chain is studied at the condition when the chain exhibits itself as a tunnel magnon transmitter. It is shown that dependently on magnon energy at the chain, a distant intercontact magnon transmission occurs either in resonant or off-resonant tunneling regime. In the first case, a transmission function depends weakly on the number of chain sites whereas at off-resonant regime the same function manifests an exponential drop with the chain length. Change of direction of external magnetic field in one of ferromagnetic contacts blocks a tunnel transmission of magnon.

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85.75.–d Magnetoelectronics; spintronics: devices exploiting spin polarized transport or integrated magnetic fields.

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1. Introduction

Modern electronics including spintronics, operates with the structures that have an effective size of the order of several tens nanometers [1–6]. Further minimization of element base for electronics is associated with molecular architecture where single molecules or their combinations have to demonstrate the properties of wires, diodes, transistors, storage cells, etc. [7–12]. In specific cases when single molecules contain paramagnetic ions, these ions can polarize an electron current through a molecule and even block the current [13–16]. The work of electronic devices is based on switching on/off the microcurrents and thus the physics of information transmission is associated with the transfer of electrons or holes. Such transfer is accompanied by a rather large energy dissipation. It is obviously that much more less power is required if the information is transmitted by uncharged carriers. In present communication, a principally new mechanism of information transmission is proposed. It is associated with a distant transfer of spin excitation (magnon) from one magnetic contact to another magnetic contact via magnetically ordered nanochain.

2. Model and theory

We consider the simplest magnetic device that consists of ferrodielectric contacts A and B connected by a ferromagnetic nanochain (AFB-device, Fig. 1). The chain involves a regular interior part and edge groups a and b coupled to respective contacts. Let μ_B be the Bohr magne-

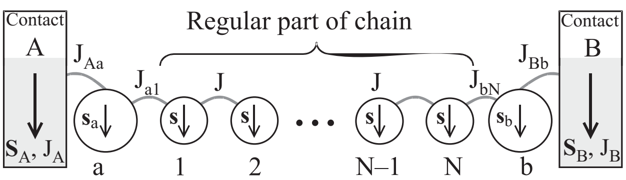

Fig. 1. Magnon transferring device. Exchange couplings in the device are characterized by parameters J_A and J_B (between sites related to ferromagnetic contacts), J_{Aa} and J_{Bb} (between edge sites of ferromagnetic chain and surface sites belonging the adjacent contacts), J_{a1} and J_{bN} (between edge sites and end sites of regular part of chain), and J (between interior sites of chain). $S_{A(B)}$, $S_{a(b)}$ and S are the spins belonging the contact sites, the edge sites of chain and the interior sites of chain, respectively.

ton and let $\hat{\mathbf{S}}_m$, D_m, g_m and $\mathbf{H}_m$ be, respectively, the spin operator, the parameter of single-ion anisotropy, the *g*-factor and the magnetic field related to device site *m*. Denoting via $J_{mn}(>0)$ the parameter that characterizes an exchange interaction between the nearest neighboring sites m and n, we represent the device's magnetic Hamiltonian in conventional form [17]

$$H = \mu_B \sum_m g_m \mathbf{H}_m \hat{\mathbf{S}}_m - \sum_m D_m (\hat{S}_m^z)^2 - \\ -\frac{1}{2}\sum_{mn} J_{mn} \hat{\mathbf{S}}_m \hat{\mathbf{S}}_n. \quad (1)$$

Ground state $|0\rangle$ of device corresponds to minimal spin projection $M_m = -S_m$ for each site m (S_m is the spin value at site m) so that $|0\rangle = \prod_m |S_m M_m = -S_m\rangle$ where $|S_m M_m = -S_m\rangle$ denotes a ground spin state for the *m*th site Ground magnetic energy of device appears as (magnetic fields are directed along axis *z*)

$$E_0 = \langle 0|H|0\rangle = -\mu_B \sum_m g_j H_m S_m - \\ -\sum_m D_m S_m^2 - \sum_{mn} J_{mn} S_m S_n. \quad (2)$$

In what follows, the lowest spin excitations (magnons) are considered only. This excitation appears at site n if the spin projection varies from $M_n = -S_n$ to $M_n = -(S_n - 1)$. Respective device state becomes $|n\rangle = |S_n M_n = -(S_n-1)\rangle \prod_{m\neq n} |S_m M_m = -S_m\rangle$. In line with theory of magnetic excitons [18–20] we introduce the operators of creation and annihilation of spin excitation as $b_n^+ = |n\rangle\langle 0|$ and $b_n = |0\rangle\langle n|$. Expanding Hamiltonian (1) with respect to these excitations one derives the following form of Hamiltonian of spin excitations

$$H_s = \sum_n \Delta E_n b_n^+ b_n + \sum_{nm} V_{nm} b_n^+ b_m \quad (3)$$

where $\Delta E_n = \langle n|H|n\rangle - E_0$ and $V_{nm} = \langle n|H|m\rangle$ are, respectively, the energy of local spin excitation in device and the matrix element characterizing the hopping of spin excitation between sites n and m. Restriction by a quadratic form over b_n^+ and b_n supposes small number of spin excitations in device. This is satisfied at condition $\langle b_n^+ b_n\rangle \ll 1$ where symbol $\langle ...\rangle$ denotes the thermodynamic average. Bearing in mind the fact that matrix element from the product $\hat{\mathbf{S}}_m \hat{\mathbf{S}}_n$ has a form

$$\langle S_n M_n', S_m M_m' | \hat{\mathbf{S}}_m \hat{\mathbf{S}}_n | S_m M_m, S_n M_n\rangle = \\ = M_m M_n \delta_{M_m, M_m'} \delta_{M_n, M_n'} + \frac{1}{2}\sqrt{(S_m + M_m)(S_m - M_m')} \times \\ \times \sqrt{(S_n - M_n)(S_n + M_n')} \delta_{M_m', M_m - 1} \delta_{M_n', M_n + 1} + \\ + \frac{1}{2}\sqrt{(S_m - M_m)(S_m + M_m')} \times \\ \times \sqrt{(S_n + M_n)(S_n - M_n')} \delta_{M_m', M_m + 1} \delta_{M_n', M_n - 1}, \quad (4)$$

one derives

$$\Delta E_n = \mu_B g_n H_n + D_n (2S_n - 1) + \sum_{m\neq n} J_{mn} S_m \quad (5)$$

and

$$V_{nm} = \langle n|H|m\rangle = -J_{nm}\sqrt{S_n S_m}. \quad (6)$$

We rewrite now a Hamiltonian of spin excitations with taken into account the fact that contacts *A* and *B* are regular structures and thus spin excitations in these structures are magnons. Let vector **n** indicates the position of site n belonging to the *r*th contact $(r = A, B)$. Using the transformation $b_n = \sum_{\mathbf{k}} T_n^{(r)}(\mathbf{k}) b_{r\mathbf{k}}$ we achieve the following diagonal form of respective Hamiltonian,

$$H_r = \sum_{\mathbf{k}} E_r(\mathbf{k}) b_{r\mathbf{k}}^+ b_{r\mathbf{k}} \quad (7)$$

where $E_r(\mathbf{k}) = E_{\rm cont}^{(r)} - z\beta_r \gamma(\mathbf{k})$ is the energy of magnon with wave vector **k** [21]. Position of the center of magnon band is determined by expression $E_{\rm cont}^{(r)} = \mu_B g_r H_r + D_r(2S_r - 1) + z\beta_r$. In a simple case of cubic crystal where the number of nearest neighbors *z* is equal to 6, one derives $\beta_r = J_r S_r$ and $\gamma(\mathbf{k}) = (1/3)(\cos ak_x + \cos ak_y + \cos ak_z)$ where S_r is the site spin in the *r*th contact, J_r is the exchange parameter for the nearest neighbors, and a is the cell constant. For a regular part of chain, we utilize an exact transformation $b_n = \sum_{\mu=1}^{N} U_{n\mu} b_\mu$ where $U_{n\mu} = (N+1)^{-1/2} \times \sin(\pi n\mu / N+1)$ Such transformation diagonalizes a Hamiltonian of interior part of nanochain yielding

$$H_{\rm reg} = \sum_{\mu=1}^{N} E_\mu b_\mu^+ b_\mu \quad (8)$$

where

$$E_\mu = E_{\rm reg}^{(0)} - 2\beta \cos\frac{\pi\mu}{N+1} \quad (9)$$

is the energy of spin excitation in regular chain with $E_{\rm reg}^{(0)} = \mu_B g H + D(2S-1) + 2\beta$ being the center of discrete magnon band. Here, g, D and J are the *g*-factor, parameter of single-ion anisotropy and exchange parameter, respectively, while $\beta \equiv JS$.

After above transformations, Hamiltonian of spin excitations appears in the form

$$H_S = H_0 + V_{\rm tr}. \quad (10)$$

The first term,

$$H_0 = H_A + H_B + H_{\rm reg} + H_a + H_b, \quad (11)$$

includes Hamiltonians related to the contacts A and B, the interior part of chain, and the edge chain sites a and b. The latter Hamiltonians read as

$$H_l = E_l b_l^+ b_l, \quad (l = a, b), \tag{12}$$

where

$$E_a = \mu_B g_a H_a + D_a(2S_a - 1) + \beta_{Aa} + \beta_{a1}, \tag{13}$$

and

$$E_b = \mu_B g_b H_b + D_b(2S_b - 1) + \beta_{Bb} + \beta_{bN} \tag{14}$$

are the energies of spin excitation at the edge sites. In Eqs. (13) and (14), we have introduced the following notations (see also Fig. 2) $\beta_{Aa} \equiv z_A J_{Aa} S_A$, $\beta_{Bb} \equiv z_B J_{Bb} S_B$ and $\beta_{a1} \equiv J_{a1} S$, $\beta_{bN} \equiv J_{bN} S$ with z_A and z_B being the number of identical contact sites coupled to the adjacent edge site. Quantities J_{Aa} and J_{Bb} are the parameters that characterize an exchange coupling of edge sites to respective contacts whereas J_{a1} and J_{bN} are the parameters related to an exchange coupling of edge sites a and b to the 1st and the Nth sites of interior part of chain, respectively. Operator

$$V_{\rm tr} = V_{Aa} + V_{ac} + V_{Bb} + V_{bc} \tag{15}$$

describes the transfer of spin excitation between edge site $a(b)$ and adjacent contact $A(B)$ as well as between the same edge site $a(b)$ and site 1(N) of regular chain (terms $V_{Aa}(V_{Bb})$ and $V_{ac}(V_{bc})$, respectively). The terms read $(rl = Aa, Bb)$

$$V_{rl} = \sum_k [\beta_{l,r\mathbf{k}} b_l^+ b_{r\mathbf{k}} + \beta^*_{l,r\mathbf{k}} b^+_{r\mathbf{k}} b_l], \tag{16}$$

and $(l = a, b)$

$$V_{lc} = \sum_{\mu=1}^{N} [\beta_{l\mu} b_l^+ b_\mu + \beta^*_{l\mu} b^+_\mu b_l]. \tag{17}$$

In Eqs. (16) and (17), the coupling parameters are defined through the relations $\beta_{l,r\mathbf{k}} = \beta_{rl} T^{(r)}_{n_l}(\mathbf{k})$ and $\beta_{l\mu} = \beta_{lm} U_{m\mu}$ with $\beta_{rl} = -J_{rl}\sqrt{S_r S_l}$ and $\beta_{lm} = -J_{lm}\sqrt{S_l S}$. Symbol $\mathbf{n}_l$ indicates the position of surface contact site coupled to the chain edge site $l = (a, b)$ coupled to respective contact $r(= A, B)$ while index $m(= 1, N)$ numbers the end site of interior part of chain. (Fig. 2 shows a relative position of magnon energies in the AFB-device along with the couplings responsible for magnon hoppings).

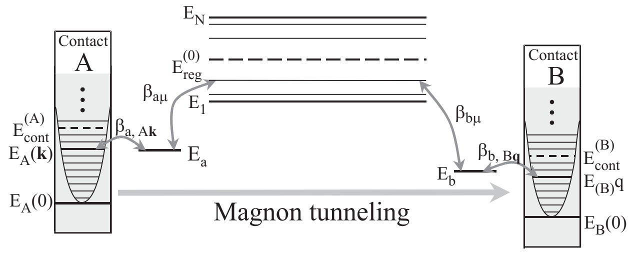

Fig. 2. Relative position of magnon energies in AFB-device. Magnon energy at contact $A(B)$ is presented in the effective mass model. Couplings of edge chain site $a(b)$ to the contact $A(B)$ and to the end site $1(N)$ of interior part of chain are characterized by quantities $\beta_{a,A\mathbf{k}}(\beta_{b,B\mathbf{q}})$ and $\beta_{a1}(\beta_{bN})$, respectively.

Our aim is to derive expression for a distant flow of magnons from one magnetic contact to another one. To this end, we suppose that interaction between nanochain and precise macroscopic contact does not distinctly perturb the contact's magnon energy $E_r(\mathbf{k})$ so that magnon vector $\mathbf{k}$ can be refer to a good quantum number. Quantum mechanics shows [22] that in a dynamic system, the probability $P_{\beta,\alpha}$ of a transition from the state α to the state β per unit time is given by expression $P_{\beta,\alpha} = (2\pi/\hbar)\,|\langle\beta|\hat{T}|\alpha\rangle|^2\,\delta(E_\alpha - E_\beta)$ where $\hat{T} = H_{\rm int} + H_{\rm int} G(E) H_{\rm int}$ is the operator for a transition on the energy shell $E = E_\alpha$. Quantity $G(E) = (E - H + i0^+)^{-1}$ is the Green's operator with $H = H_0 + H_{\rm int}$ being the Hamiltonian of entire dynamic system. In the case of distant magnon transmission under consideration, the states α and β are associated with magnon wave vectors $\mathbf{k}$ and $\mathbf{q}$. Therefore, a probability to transfer a separate magnon from the contact A to the contact B is given by expression $P_{A\mathbf{k},B\mathbf{q}} = (2\pi/\hbar)\,|T_{B\mathbf{q},A\mathbf{k}}|^2\,\delta(E_A(\mathbf{k}) - E_B(\mathbf{q}))$ where $T_{B\mathbf{q},A\mathbf{k}} = \langle B\mathbf{q}|V_{\rm tr} G(E) V_{\rm tr}|A\mathbf{k}\rangle$, $E = E_A(\mathbf{k})$, and $G(E) = (E - H_s + i0^+)^{-1}$. Since the device is an open quantum system, an integral transmission probability $P_{A\to B}$ appears as the sum of probabilities $P_{A\mathbf{k},B\mathbf{q}}$ each weighted with magnon distribution function $W_A(E_A(\mathbf{k}))$. Thus,

$$P_{A\to B} = \sum_{\mathbf{kq}} W_A(E_A(\mathbf{k})) P_{A\mathbf{k},B\mathbf{q}}. \tag{18}$$

Analogous form is valid for reverse probability $P_{B\to A}$ (in Eq. (18), one has only to substitute $W_A(E_A(\mathbf{k}))$ for the $W_B(E_B(\mathbf{q}))$).

Let transform now Eq. (18) to more convenient form. Bearing in mind that exchange interaction couples only the nearest neighbors one derives $T_{B\mathbf{q},A\mathbf{k}} = \beta_{b,B\mathbf{q}} G_{ba}(E) \beta^*_{a,A\mathbf{k}}$ where $G_{ba}(E) = \langle b|(E - H_s + i0^+)^{-1}|a\rangle$ is the quantity that establishes a coupling between spin states of spatially separated edge sites a and b. Its form is similar those used in theory of elastic electron transmission through organic molecules [23,24]. Following the method derived in Ref. 24 we reduce exact Hamiltonian H_s to the $H_s^{(\rm eff)} = \sum_{r=A,B} H_r + H^{(\rm eff)}_{\rm chain}$ where contact Hamiltonians conserve their form (7) whereas the effective chain Hamiltonian reads

$$H^{(\rm eff)}_{\rm chain} = \sum_\lambda \mathcal{E}_\lambda b_\lambda^+ b_\lambda. \tag{19}$$

Here, $\mathcal{E}_\lambda$ is the magnon energy in proper state λ of Hamiltonian (19), $b_\lambda = \sum_j \Theta_{j\lambda} b_j$ and $b_\lambda^+ = \sum_j \Theta^*_{j\lambda} b_j^+$ are new operators of annihilation and creation of magnon in the chain, and $\Theta_{j\lambda} = \langle j|\lambda\rangle$ are the elements of matrix that transforms chain states $j(=a,b,\mu)$ formed at $V_{a1} = V_{bN} = 0$ and $V_{Aa} = V_{Bb} = 0$, into proper states λ formed with taken into consideration off-diagonal interaction (15). Substitution of Hamiltonian H_s for the $H_s^{(\mathrm{eff})}$ yields

$$G_{ba}(E) = \sum_\lambda \frac{\Theta_{b\lambda}\Theta_{\lambda a}}{E-\mathcal{E}_\lambda}. \qquad (20)$$

Note an important fact that proper chain energy $\mathcal{E}_\lambda$ contains an image addition caused by interactions of edge chain sites with macroscopic contacts (operators V_{aA} and V_{bB} in Eq. (15)). As an example, we consider the case where exchange interaction of edge sites a and b with adjacent contacts and interior part of chain does not exceed exchange interactions within the contacts as well as within the interior part of chain. At such conditions, a mixture of extended states $|A\mathbf{k}\rangle, |B\mathbf{q}\rangle$ and $|\mu\rangle$ with localized states $|a\rangle$ and $|b\rangle$ is not large. This allows one to reduce exact form (20) to the expression

$$G_{ba}(E) \simeq \frac{\beta_{a1}\beta_{bN}}{(E-\mathcal{E}_a(E))(E-\mathcal{E}_b(E))} \times \sum_{\mu=1}^{N} \frac{U_{1\mu}U_{N\mu}}{E-\mathcal{E}_\mu(E)} \qquad (21)$$

where $\mathcal{E}_j$ is the proper chain energy for magnon states $j = a, b, \mu$. Proper energy is derived from relation $\mathcal{E}_j(E) = E_j + \Sigma_j(E)$ with

$$\sum_j(E) = \sum_{r=A,B}\sum_{\mathbf{k}} \frac{|\beta_{j,r\mathbf{k}}|^2}{E - E_r(\mathbf{k}) + i0^+} \qquad (22)$$

being the magnon self-energy. Self-energy characterizes the influence of macroscopic contacts on the chain through exchange couplings $\beta_{j,r\mathbf{k}}$. Real part of self-energy determines a small alteration of energies and can be omitted. It is not the case for image part which plays a fundamental role in magnon transmission. Thus, in Eq. (21), magnon chain energies appear as

$$\mathcal{E}_j(E) \simeq E_j - i\Gamma_j(E)/2 \qquad (23)$$

where quantities E_j are defined through expressions (9), (13), and (14) while image additions read ($l = a(b)$ if $r = A(B)$)

$$\Gamma_l(E) = 2\pi\sum_{\mathbf{k}} |\beta_{l,r\mathbf{k}}|^2 \delta(E - E_r(\mathbf{k})), \qquad (24)$$

and ($\mu = 1,\ldots N$)

$$\Gamma_\mu(E) = 2\pi \sum_{r=A,B}\sum_{\mathbf{k}} |\beta_{\mu,r\mathbf{k}}|^2 \delta(E - E_r(\mathbf{k})). \qquad (25)$$

Couplings $\beta_{a,A\mathbf{k}}$ and $\beta_{b,B\mathbf{k}}$ have been written above whereas $\beta_{\mu,r\mathbf{k}} = \langle\mu|V_{\mathrm{tr}}G(E)V_{\mathrm{tr}}|r\mathbf{k}\rangle = \beta_{l,r\mathbf{k}}\beta^*_{l\mu}/(E-\mathcal{E}_l)$, ($l = a(b)$ if $r = A(B)$).

Quantity $Q_{A\to B} = P_{A\to B} - P_{B\to A}$ characterizes a normalized net flow of magnons. With introduction of width parameters (24) and (25), this flow can be represented in form

$$Q_{A\to B} = \frac{1}{2\pi\hbar}\int_{-\infty}^{+\infty} dE\, T(N,E) \times (W_A(E) - W_B(E)) \qquad (26)$$

where

$$T(N,E) = \Gamma_b(E)\,|G_{ba}(E)|^2\, \Gamma_a(E) \qquad (27)$$

is the transmission function that specifies a dynamics of direct contact-contact transfer of single magnon dependently on both the number of chain sites and the character of exchange couplings within the AFB-device.

3. Results and discussion

Magnon flow (26) depends strongly on precise form of distribution functions $W_A(E)$ and $W_B(E)$ as well as transmission function (27). To specify distribution function one has to know a regime of magnon formation in the contacts. This problem requires a separate consideration. In this communication, we discuss only the properties of transmission function. To this end, let rewrite the $T(N,E)$ in more detail form

$$T(N,E) = \frac{\Gamma_a(E)\beta_{a1}}{[(E-E_a)^2 + \Gamma_a^2(E)/4]} \times \frac{\Gamma_b(E)\beta_{bN}}{[(E-E_b)^2 + \Gamma_b^2(E)/4]} \left[\left(\sum_{\mu=1}^{N} \frac{U_{1\mu}U_{N\mu}(E-E_\mu)}{(E-E_\mu)^2 + \Gamma_\mu^2(E)/4}\right)^2 + \left(\sum_{\mu=1}^{N} \frac{U_{1\mu}U_{N\mu}(\Gamma_\mu(E)/2)}{(E-E_\mu)^2 + \Gamma_\mu^2(E)/4}\right)^2\right]. \qquad (28)$$

Bearing in mind that, generally, the magnons are generated at $k \approx 0$, the widths can be calculated in the effective mass approximation with taken into account the fact that $E \ge E_r(0)$. Calculations yield

$$\Gamma_l(E) = \frac{1}{2\pi}\frac{\beta_{rl}^2}{\beta_r}\sqrt{\frac{E-E_r(0)}{\beta_r}}, \quad (r = A(B), l = a(b)) \qquad (29)$$

and

$$\Gamma_\mu(E) = \frac{\sin^2[\pi\mu/(N+1)]}{N+1}\times$$
$$\times\left[\frac{\beta_{a1}^2\Gamma_a(E)}{(E_\mu - E_a)^2 + \Gamma_a^2(E)/4} + \frac{\beta_{bN}^2\Gamma_b(E)}{(E_\mu - E_b)^2 + \Gamma_b^2(E)/4}\right]. \quad (30)$$

Figure 3 manifests a typical dependence of transmission function on magnon energy $E = E_A(\mathbf{k}) = E_B(\mathbf{q})$. The peaks appear at elastic resonant transmission regime when magnon energy at the contacts coincides exactly with magnon energies at the ferromagnetic chain. The coincidence occurs at condition $E = E_j$, $(j = a, b, \mu)$. Broadening the peaks is completely determined by quantities (29) and (30). It is necessary to note an important fact that independently on the number of chain sites, the peak's heights differ insignificantly from each other. It is not the case at off-resonant transmission regime. As it follows from Fig. 4, at such regime, a transmission function exhibits an exponential drop showing, thus, the tunneling like behavior. Respective analytical expression for transmission function follows from Eq. (28) if one sets $(E - E_\mu)^2 \gg \Gamma_\mu^2(E)/4$. Then at $|E_{\rm reg}^{(0)} - E| \geq 2\beta$ one derives

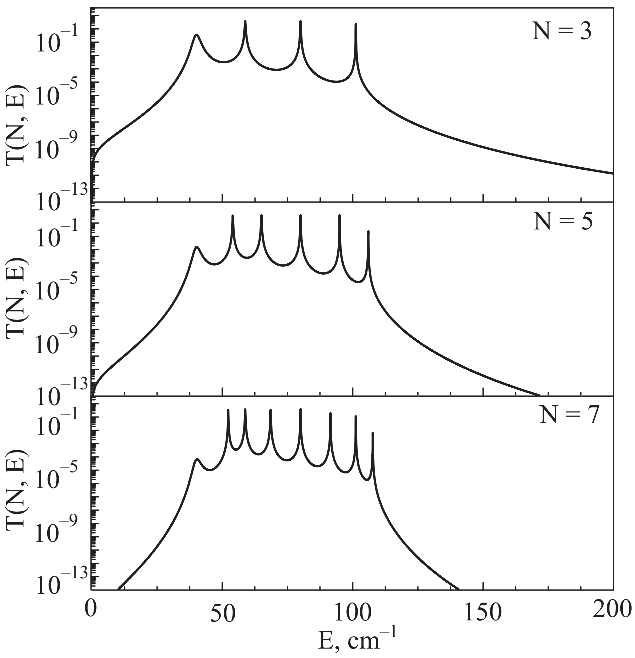

Fig. 3. Behavior of transmission function at different length of ferromagnetic chain. Peaks correspond to such transmission energies that coincide with magnon energies within the ferromagnetic chain of $N+2$ sites (regime of resonant tunneling). The curves are calculated in using Eq. (28) with $\beta_A = \beta_B = \beta_{Aa} = \beta_{Bb} = \beta_{a1} = \beta_{bN} = 10\ {\rm cm}^{-1}$, $\beta = 15\ {\rm cm}^{-1}$, $E_{\rm reg}^{(0)} = 80\ {\rm cm}^{-1}$, $E_A(0) = E_B(0) = 80\ {\rm cm}^{-1}$, $E_a = E_b = 40\ {\rm cm}^{-1}$.

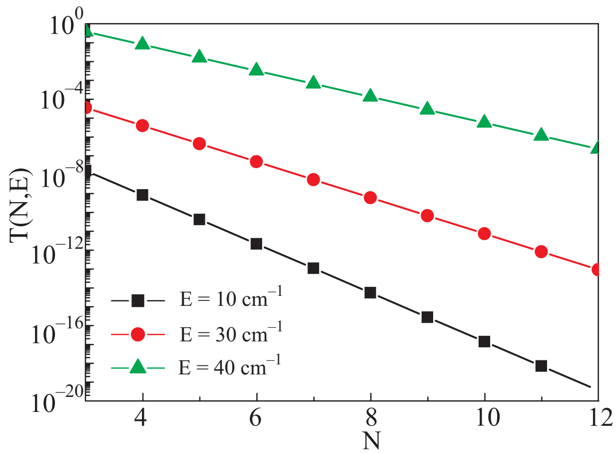

Fig. 4. Off-resonant regime of magnon tunneling. At fixed transmission energy, the transmission function drops exponentially when the number of chain sites increases. The curves are calculated in using Eq. (28) with the same parameters as those for Fig. 3.

$$T(N,E) = D(E)\times$$
$$\times\frac{\Gamma_a(E)\Gamma_b(E)(\beta_{a1}^2\beta_{bN}^2/\beta^2)}{[(E-E_a)^2 + \Gamma_a^2(E)/4][(E-E_b)^2 + \Gamma_b^2(E)/4]} \quad (31)$$

where we have introduced a specific superexchange decrease factor

$$D(E) = \frac{\sinh\zeta(E)}{\sinh[\zeta(E)(N+1)]} \quad (32)$$

with

$$\zeta(E) = \ln\left[\frac{|E_{\rm reg}^{(0)} - E|}{2\beta} + \sqrt{\left(\frac{E_{\rm reg}^{(0)} - E}{2\beta}\right)^2 - 1}\right] \quad (33)$$

being the decrease parameter. When $\exp\zeta(E) \gg 1$ the decrease factor reduces to simple form $D(E) \simeq \exp[-\zeta(E)N]$ reflecting thus an exponential drop of transmission function. The drop strongly depends on transmission gap $|E_{\rm reg}^{(0)} - E|$.

It is seen from Fig. 4 that the less is the gap, the slower drop of transmission function. For instance, if generation of magnons in contact A occurs near the bottom of magnon band so that magnon distribution function $W_A(E)$ has a maximum value at $k \simeq 0$, then the main contribution in integral of expression (26) give the energies of the order $E \simeq E_A(0)$ and thus, $Q_{A\to B} \sim \exp[-\zeta(E_A(0))N]$.

4. Conclusion

In this communication, we propose a physical mechanism for a coherent distant transmission of spin excitation (magnon) from one magnetic contact to another magnetic contact via a linear ferromagnetic chain embedded between the contacts, Fig. 1. Coupling of structure units in such device is performed through the Heisenberg's site-site exchange interaction which is also responsible for a magnon hopping within the device. It is assumed that a magnon transit-time is mach less the magnon life-time and, thus, one can describe a magnon transmission as a stationary transfer process. Zero temperature case is considered only so that a temperature excitation of magnons is ignored. It is assumed that generation of magnons in ferromagnetic contacts is caused by an external source. But, the concentration of magnons is too small that the use of single-magnon model is quite enough to describe a magnon transmission between the contacts. We show that a ferromagnetic chain is able to form a distant (superexchange) coupling $T_{B\mathbf{q},A\mathbf{k}}$ between single-magnon states $|A\mathbf{k}\rangle$ and $|B\mathbf{q}\rangle$ related to different contacts. The character of superexchange coupling depends strongly on value of magnon energies $E_r(\mathbf{k})$ and E_j at the *r*th contact and at the chain, respectively (see Fig. 2). When magnon energy $E = E_A(\mathbf{k}) = E_B(\mathbf{q})$ coincides with the E_j, transmission function $T(N,E)$ demonstrates the presence of resonant peaks well seen at the Fig. 3. Appearance of the peaks indicates an effective coherent contact-contact magnon transfer independently of the number of chain sites. Another situation occurs if the contact's magnon energy differs from the chain's magnon energy. In this case, a transmission function drops exponentially with increase of chain length, Fig. 4. Such exponential drop corresponds to a tunnel mechanism of transmission and, thus, one can say about magnon tunneling. Magnon transmission in the AFB-device under consideration is strongly controlled by an external magnetic field. For instance, let one change a direction of magnetic field applied to one of the contacts (or to the chain). After such change, a direction of spins in the contact and the chain becomes opposite. As a result, the hopping matrix element (4) vanishes, and magnon hopping from the contact to the chain is blocked.

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