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THE ELECTRON TRANSPORT PROPERTIES IN A <FERROMAGNETIC> CHAIN INCLUDING THE MAGNETIC DEFECT

The scattering of an unpolarized electron wave is considered on a film consisting of N periodic ferromagnetic nanolayers separated by nonmagnetic layers. The layer materials are chosen, so that the potential relief of the structure consists of N identical magnetized barriers separated by nonmagnetic quantum wells. The entire system consists of two "magnetic domains" with parallel magnetizations separated by a barrier with noncoplanar magnetization.

Keywords: resonant tunneling, valve effect, spin polarization, “noncoplanar defect”, Zeeman splitting.

INTRODUCTION

The transport properties in various structures containing magnetic nanolayers are taking place in the presence of preferred noncollinear or noncoplanar directions, for example, due to the differences in the direction of the magnetization in variouss nanolayers. This circustance leads to two-channel scattering processes of the electron wave - without and with a spin flip. The amplitudes of the forward and backward scattering, and, therefore, the transport characteristics can strongly depend on certain quantities that determine the mutual orientation of these distinct (preferred) directions (noncollinear or noncoplanar degrees of freedom). A spin-valve, GMR and TM are examples of characteristic effects of simiar nature [1-3]. Another example of noncollinearity effect is considered in Ref. [4]. The noncollinearity effects [5] which arise in the scattering of a polarized wave on an isolated magnetized barrier were investigated in [6, 7]. The transmission coefficient and the degree of spin polarization of the transmitted incident nonpolarized wave electron wave through a system consisting of two identical barriers with noncollinear magnetizations was also investigated. The transport characteristics of a two-barrier noncoplanar system were calculated [8].

STATEMENT OF THE PROBLEM

Below we consider the scattering of a nonpolarized electron wave on a system of N identical magnetic barriers spaced equidistant from each other and separated by nonmagnetic quantum wells. Each of the barriers is characterized by the induction vector of the internal magnetic field with the following configuration: the first $n-1$ and the last $N-n$ barriers are magnetized so that their internal magnetic field vectors are parallel, and the internal field of the n-th barrier is oriented noncoplanar towards the internal fields of the $N-1$ barriers.

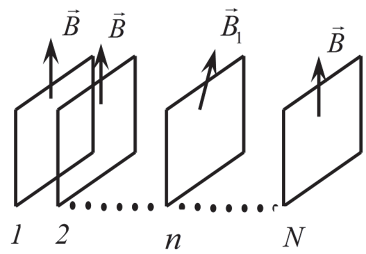

Fig. 1. The scheme of a structure containing N magnetic nanolayers: the internal magnetic fields of $N-1$ layers are parallel to each other, and the internal field of the n-th layer is noncoplanar towards them

It is important to note that the width of the quantum wells is so great that the exchange interaction between two adjacent (neighboring) wells is missing. Thus, the whole system is divided into two "ferromagnetic domains", of length $n-1$ and $N-n$, and they are separated by a "noncoplanar defect". This can be a real defect that occurs when a ferromagnetic nanolayer is deposited, however, can be created artificially. Whether it makes sense to create such an artificial defect, will show the final results, that is, the properties of the degree of polarization of the transmitted wave, which is a function of noncoplanar degrees of freedom, as well as the coordinates of the "defect" (the number of the corresponding barrier).

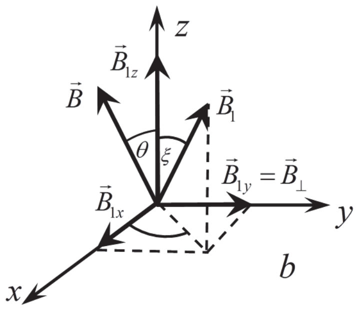

Fig. 2. The configuration of the internal field in the n – th layer. It is further assumed that $B = B_1$

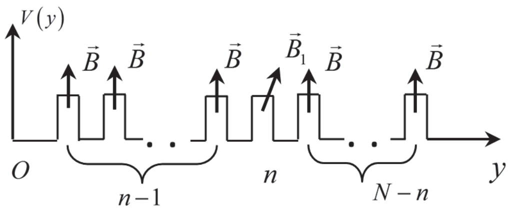

Fig. 3. Potential relief of the discussed system. It contains N identical magnetic barriers spaced equidistant from each other and separated by nonmagnetic quantum wells. $\vec{B}_1$ and $\vec{B}$ are noncoplanar

DISCUSSION

To construct the plots of the degree of polarization dependences on various variables, we use the following approximating interaction Hamiltonian:

$$H_{\text{int}} = \left(\omega - \gamma B\sigma_z\right)\sum_{\ell=1}^{N}{}' \delta\left(y-\ell\right) + \left(\omega - \gamma \vec{B}_1\vec{\sigma}\right)\delta\left(y-n\right),$$

given in dimensionless quantities: $\omega = \Omega / E_0 a$, Ω - is the "amplitude" of the δ - potential, $\gamma = \mu / 2E_0$, μ - is the electron magnetic momentum, $E_0 = \hbar^2 / 2ma^2$, a - is a constant of the order of atomic dimensions, the prime on the sum sign denotes the absence of the term with $\ell = n$; this term is presented separately; it describes the interaction of the electron spin with a "noncoplanar defect", y - is a dimensionless coordinate variable.

Below are the graphs for $N = 7$, i.e. a system containing seven magnetized barriers. The degree of polarization of the transmitted wave depends on three variables: the degree of noncollinearity - the angle θ between the z axis and the component of the vector $\vec{B}_1$ on the plane of the nanolayer, the ratio $\eta = B_\perp / B_{1z}$ of the two components of the "defect" internal field, and the momentum of the electron wave k. Two variables are fixed and the dependence of the polarization on the third variable is constructed.

Let us first consider the degree of polarization in scattering by a 7-barrier system, when the internal fields of all the barriers are directed in the same way (a single-domain system).

This is necessary for comparison with the corresponding plot of our problem.In this case, the dependence $P = P(k)$ is a sequence of peaks, some of which reach a maximum.

In this case, the scattering channel with the spin flip is closed $(T_{\uparrow\downarrow} = T_{\downarrow\uparrow} = 0)$, and the degree of polarization is equal to:

$$P(k) = |P_z(k)| = \frac{|T_{\uparrow\uparrow}|^2 - |T_{\downarrow\downarrow}|^2}{|T_{\uparrow\uparrow}|^2 + |T_{\downarrow\downarrow}|^2},$$

where $T_{\uparrow\uparrow}$, $T_{\downarrow\downarrow}$ - are the amplitudes of transmission without a spin flip. At the partial resonance of transmission, for example, $|T_{\uparrow\uparrow}| = 1$, $|T_{\downarrow\downarrow}| << 1$, and then $P(k) = 1$ up to small terms. Thus, the maximum spin polarization is achieved only at partial resonance of transmission. Furthermore $P(k)$, as well as the envelope of local maxima are periodical functions (Fig.4).

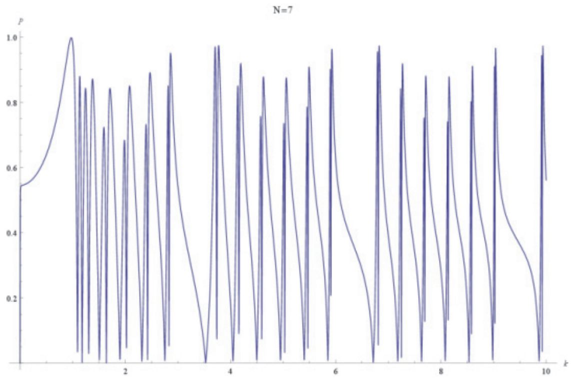

Fig. 4. The dependence of the transmitted wave polarization degree on the momentum k *of the system with parallel internal fields* $(\eta = 0;\ \theta = 0)$

In the case, when there exists a "noncoplanar defect" in the system, the picture changes significantly. In the region of small k, peaks are again present on the plot, however, in the region of large k, there arise peculiar "windows of polarization" - the range of values k, where $P(k)$ change quite slowly, and besides its numerical value is close to unity. These ranges of values k are separated by narrow regions, in which $P(k)$ is practically zero. Because of the presence of a second scattering channel-with a spin flip, the squares of the transmission amplitude modules are rapidly oscillating functions of k, the period of which is $\pi/2N$, hence $\pi/14$ - in our case; as a result, the curve in Fig.4. is the envelope of the maxima of these oscillations.

Wherein $P(k)$ varies very slowly with the values η and θ. $P(k)$ weakly depends on the "defect" coordinate. From Fig.5 it is clear that for large k this dependence simply disappears.

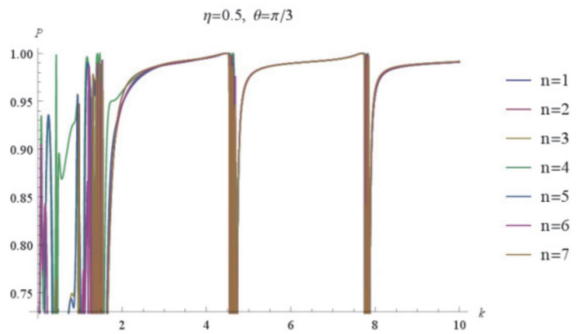

Fig. 5. The dependence of $P(k)$ *in case of the presence of a "noncoplanar defect"*

The degree of polarization is a 2π -periodic function of θ. With increasing η, the amplitude decreases, i.e. suppression of 2π -oscillations occurs. The degree of polarization is a slowly varying function of η, and at large η it reaches the plateau; except this, there is a significant dependence on the coordinate of the "defect".

CONCLUSION

From the results presented, it can be seen that the proposed system has spin-polarizing properties. In the region of sufficiently large k there exist "spin-polarization windows" in which the degree of polarization depends weakly on the momentum k, and is close to unity. Two "neighboring windows" are separated by narrow ranges of values k, in which the degree of polarization is zero. The degree of polarization is a 2π -periodic function of the angle θ. The growth of the parameter η leads to the suppression of 2π -oscillations. $P(\theta)$ essentially depends on the coordinate of the "defect". $P(\eta)$ is a slowly varying function of the parameter η; for large η, $P(\eta)$ goes to the plateau, and, in addition, it essentially depends on the coordinate of the "defect".

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Ա.Ս. ՍԱՀԱԿՅԱՆ

ԷԼԵԿՏՐՈՆԻ ՏՐԱՆՍՊՈՐՏԱՅԻՆ ՀԱՏԿՈՒԹՅՈՒՆՆԵՐԸ ՄԱԳՆԻՍԱԿԱՆ ԱՐԱՏ ՊԱՐՈՒՆԱԿՈՂ ՖԵՐՈՄԱԳՆԻՍԱԿԱՆ ՇՂԹԱՆԵՐՈՒՄ

Դիտարկվում է չբևեռացված էլեկտրոնային ալիքի ցրումը N հատ պարբերական ֆերոմագնիսական նանոշերտերից բաղկացած և միմյանցից ոչ մագնիսական շերտերով առանձնացված թաղանթի վրա: Թաղանթը կազմող նյութերն ընտրվում են այնպես, որ կառույցի պոտենցիալ ռելիեֆը կազմված լինի N նույնական մագնիսացված արգելքներից, որոնք առանձնացված են ոչ մագնիսական քվանտային հորերով: Ամբողջ համակարգը բաղկացած է երկու զուգահեռ մագնիսացումներով մագնիսական դոմեններից, որոնք բաժանված են ոչ կոմպլանար մագնիսացմամբ արգելքով:

Առանցքային բառեր. ռեզոնանսային թունելավորում, փականի էֆեկտ, սպինային բևեռացում, ոչ կոմպլանար արատ, Զեեմանի տրոհում:

А.С. СААКЯН

ТРАНСПОРТНЫЕ СВОЙСТВА ЭЛЕКТРОНА В “ФЕРРОМАГНИТНЫХ” ЦЕПОЧКАХ, ВКЛЮЧАЮЩИХ МАГНИТНЫЙ ДЕФЕКТ

Рассмотрено рассеяние неполяризованной электронной волны на пленке, состоящей из N периодических ферромагнитных нанослоев, разделенных немагнитными слоями. Материалы слоев выбираются таким образом, чтобы потенциальный рельеф структуры состоял из N одинаковых намагниченных барьеров, разделенных немагнитными квантовыми ямами. Вся система состоит из двух "магнитных доменов" с параллельными намагниченностями, разделенных барьером с некомпланарной намагниченностью.

Ключевые слова: резонансное туннелирование, вентильный эффект, спиновая поляризация, "некомпланарный дефект", зеемановское расщепление.