TUNNELING BETWEEN FERROMAGNETIC FILMS

M. JULLIERE

Institut National des Sciences Appliquées, 35031 Rennes Cedex, France

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Fe-Ge-Co junctions conductance G(V) is studied when mean magnetizations of the two ferromagnetic film are parallel or antiparallel. Conductance measurement, in these two cases, is related to the spin polarizations of the conduction electrons.

We have observed zero bias anomalies of the Appelbaum-Anderson type as a systematic feature of the tunneling conductance $G(V)$ of Fe-Ge-Pb and Fe-Ge-Co tunnel junctions, at $T \leqslant 4.2$K. The conductance dip can be due to exchange scattering of the tunneling electrons by magnetic atoms. These atoms are diffused in the semiconductor tunnel barrier or located at the Fe-Ge interface. The anomaly, typically of 4 mV width, is independent of applied magnetic field. This is explained by interactions between localized moments (magnetic atoms) resulting in an large effective magnetic field, as described by Wyatt [3].

An artificial barrier was chosen to minimize magnetic coupling between ferromagnetic electrodes. Furthermore, the distance between electrodes (from 100 to 150 Å) makes "orange peel coupling" [4] very weak. To prevent shortings, produced by pinholes in the Ge film, the samples were oxidized at room temperature, in dry oxygen, after semiconductor deposition. Barrier height, deduced from $G(V)$ curves (fig. 1), is of the order 100 meV. Therefore we can assume that tunneling is through the semiconductor.

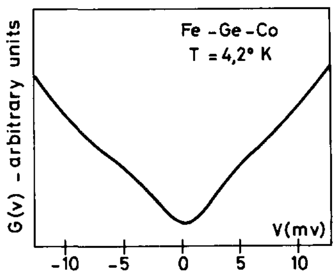

Fig. 1. Conductance versus voltage of Fe-Ge-Co junctions at 4.2K. Ge layer width is about 100 Å.

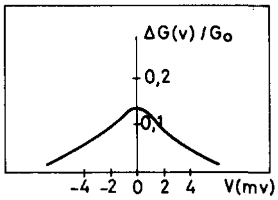

Fig. 2. Relative conductance $(\Delta G/G)_{V=0}$ of Fe-Ge-Co junctions at 4.2K. ΔG is the difference between the two conductance values corresponding to parallel and antiparallel magnetizations of the two ferromagnetic films.

A d.c. magnetic field was applied during ferromagnetic thin films deposition, to obtain a single domain behaviour. Furthermore, the two films have the same easy axis of magnetization, but different coercive fields. Such properties permit to make their magnetizations antiparallel, when applied magnetic field value is included between these two coercive fields.

Observation of "Fe-Ge-Pb" $G(V)$ curve shows that conduction is due to tunneling electrons. The "Fe-Ge-Co" $G(V)$ curve, obtained under the same conditions, present a similar aspect: so we can deduce that tunneling is mainly responsible of conduction in this case. At zero bias voltage, the first order term in conductance anomaly, $G_{\text{sf}}^{(2)}$, is zero after Appelbaum [2]. So we can assume, in first approximation, that electrons tunnel without spin flip at this voltage. Then, following Tedrow and Meservey's [5] analysis, the Fe-Ge-Co junction conductance $F(V=0)$ is proportional to:

$$aa' + (1-a)(1-a'),$$

with parallel magnetizations in the Fe and Co films and to:

$$a(1-a') + a'(1-a),$$

with antiparallel magnetizations.

a and a' are the fractions of tunneling electrons in iron and cobalt respectively whose magnetic moments are parallel to the magnetization.

This spin conservation hypotheses gives a relative conductance variation $\Delta G/G = 2PP'/(1+PP')$, where $P=2a-1$ and $P'=2a'-1$ are the conduction electrons spin polarizations of the two ferromagnetic metals. Measured values of ΔG versus applied voltage V are shown on fig. 2. ΔG decreasing can be explained by spin-flips taking place at metal-barrier interfaces.

Maximum measured value $(\Delta G/G)_{V=0}$ is about 14%. From Tedrow and Meservey [6] measurements ($P = 44\%$ and $P' = 34\%$), on $Al\text{-}Al_2O_3$-ferro junctions, we have deduced $\Delta G/G = 26\%$.

This discrepancy can be explained by magnetic couplings between ferromagnetic films as well as by spin-flip part $G_{sf}^{(3)}$ of second order conductance anomaly.

References

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