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Giant Magnetoresistance and Oscillations In Interlayer Exchange Coupling In Co/Cu/Co Multi-Layers

Haji Shirinzadeh

Department Semiconductors (Device Fabrication), Surface Physics and Thin Films
Material And Energy Research Center (MERC) Alvand Avenue,
Postal Code: 13145-1659, Tehran, Iran

E-mail: h_szadeh@merc.ac.ir

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ABSTRACT

The oscillations in interlayer exchange coupling between ferromagnetic layers which are Separated by a nonmagnetic spacer layer, manifests n oscillatory magnetic properties which depend on the thickness of Copper interlayer. Using Molecular Beam Epitaxy system. We have made multilayer films with alternating cobalt and copper thin films. The preliminary results are reported on microstructure and magnetization properties. The conductance between first and third film depends on the relative orientation of magnetization between them. This optimizes to large magneto resistance changes called Giant Magneto-resistance effect.

Keywords: Thin films, Multilayers, Interlayer, Exchange Coupling, Sputtered

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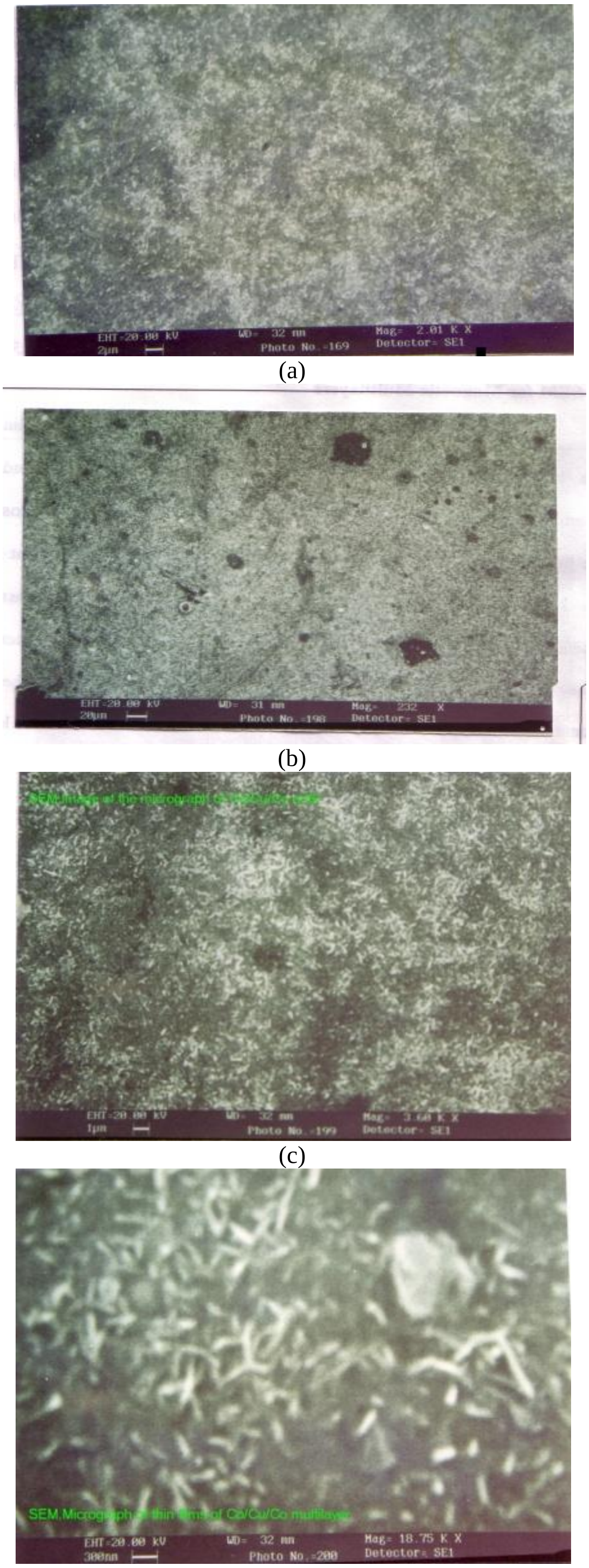
INTRODUCTION

The sandwiches of alternating magnetic and normal Co/Cu,and Ferro-and Anti ferromagnetic layer Fe/Cr exhibit large negative magneto-resistance under a moderate magnetic field Development of such systems assumes immense importance as they are potential candidates for replacing the inductive read/write heads being used in several-devices. The origin of the magneto-resistivity lies in the magnetic exchange interactions amongst the layers and the related electrical charge transport behavior. Sandwiches are of Fe/Cr system represent two magnetic layers separated by another type of magnetic layer (Baibich et al., 1988). The strength of the interaction defends on the thickness of the non-magnetic layer. The exchange interaction between two ferromagnetic layers turns from ferromagnetic to anti ferromagnetic. Below a critical thickness $t_{Cr} \approx 12$Å, the interaction between two Fe layers develops an anti ferromagnetic spin structure. The charge carrier scattering is less along the direction of magnetization. The charge transport within a Single ferromagnetic layer is aided by the magnetic exchange interaction .Obviously, in two different layers the charge transport is carried-to two opposite directions which yields high resistivity across the entire multilayer system under a certain applied magnetic field. Moreover, the spin flipping along the direction of the applied field leads to strong intra- as well as interlayer ferromagnetic coupling. The spin-spin scattering, therefore, is strongly suppressed which yields large drop in resistivity. The drop in resistivity attains maximum at the coercive field limit during which the spin flipping develops a ferromagnetic pin structure a cross the multilayer system. Beyond the coercive field, no further drop can be observed because of the saturation of the spin flipping. Since the first study in this regard (Baibich et al., 1988), many significant observations have been made (Bloemen, Van Dalen, De Jonge, Johnson, & Aan de Stegge, 1993; Celotta, Pierce, & Unguris, 1995; Speriosu, Dieny, Humbert, Gurney, & Lefakis, 1991; Yang & Scheinfein, 1995) which show that the magneto resistance depends on the nature of the exchange coupling between two magnetic layers (which, in turn, depends on the thickness of the intermediate non-magnetic layer), current flow configuration (current-in-plane or current-perpendicular-plan) (Bass & Pratt Jr, 1999), magnetic anisotropies of the interface and bulk region (Johnson, Bloemen, Den Broeder, & De Vries, 1996) etc. Although, anti-ferromagnetic spin structure across the magnetic bi-layer yields high magneto resistivity in the multilayer systems, there have been quite a few studies which show that apart from 180^0 misalignment in spin orientation high order 90^0 misalignment can also take place. This is the result of variation in the non-magnetic layer thickness and associated variation in the bulk and interface anisotropies. Obviously, for 90^0 spin alignment, the overall scattering cross-section within and across the magnetic layers is less which yields smaller magneto resistivity. By suitably varying the thickness of the non-magnetic layer, it has been shown that the exchange coupling follows an oscillatory pattern with the nature of the coupling varying between anti-ferromagnetic and ferromagnetic alignment. The period of oscillation is found to be I nm. The pattern can be fitted in the equation.

$$J(t_{CU}) \sim (\frac{1}{t_{Cu}^2}) \sin\frac{2\tau t_{Cu}}{\lambda} + \psi_1) + r sin\left(\frac{2r t_{Cu}}{\lambda} + \psi_2\right) \qquad (1)$$

where t_{Cu} is the thickness of the Cu layer in between two Co layers, λ_1 *and* λ_2 are the periodicities. Although in some studies it has been shown (Bloemen, 1996) that the oscillatory coupling strength J leads to oscillatory magneto resistance, in one study it has been pointed out (Speriosu et al., 1991) that the oscillatory coupling strength is not accompanied by oscillatory amplitude of magneto resistance. This has been achieved through a spin-valve type magneto resistive multilayer arrangement in which the magnetization in one Co layer can be fixed through interaction with another film. Variation of the magnetization in two Co layers as independent of the sign of the exchange coupling which shows that the magnetoresistance drops slowly with the increase in the thickness of the non-magnetic layer. The magneto resistance is found to depend on the configuration of current flow (Bass & Pratt Jr, 1999). The current-in-plane configuration considers mostly the electrons traversing within each layer. The mean free paths over which the electrons retain their spin memory (in other words, the scattering does not destroy the spin orientation of the electrons) both in the metallic non-magnetic and magnetic layers are designated by1_N, $1_F^{\uparrow}$, and $1_F^{\downarrow}$ (where ↑ and ↓ symbol signify spin-up and spin-down states) and superscript N, F signify the normal and ferromagnetic layers. These mean free paths are shorter than the film dimension scales and the resistance depends on them exponentially in a very complex way. On the other hand, in the current-perpendicular-plane arrangement, each electron traverses across the multilayer and experiences the spin structure (ferromagnetic or anti ferromagnetic) in a different way. The spin diffusion lengths in this arrangement are longer than the layer thickness t_N andt_F. The resistance is found to depend on t_N and t_F linearly (Valet & Fert, 1993). The magnetoresitancies found to be larger in the current-perpendicular-plane arrangement.



(a)

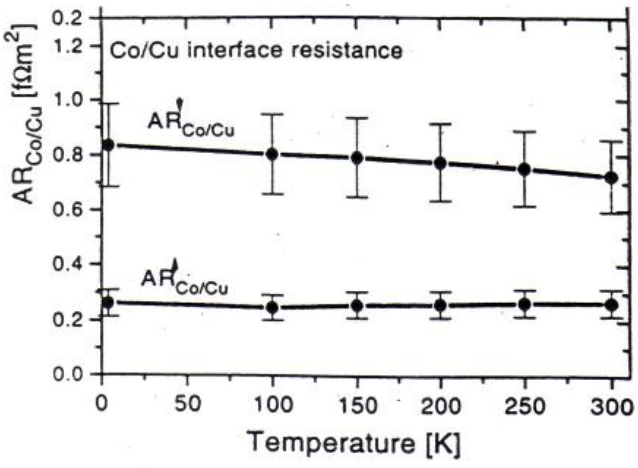
(b)

(c)

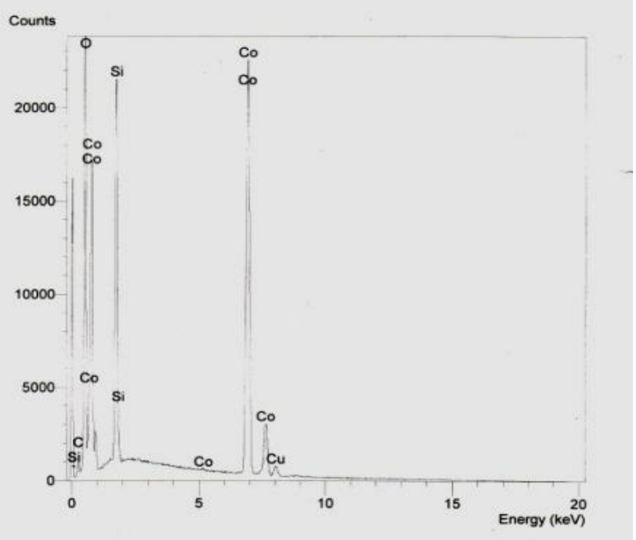
(d)

Fig.1 The microstructure of the multilayer for samples with different annealing temperatures.

The magnetic anisotropies too, influence the magneto resistivity of the multilayer systems. The anisotropy is defined by the difference in the energy required to magnetize the crystal along different crystallographic axes; thus, determining the magnetic "easy" and "hard" axis. In the case of the multilayer system, the interface anisotropy leads to the rotation of the magnetization "easy" axis from in-plane to perpendicular to the plane orientation the overall anisotropy energy depends on the bulk and surface anisotropy energies following $K = K_V + K_S/t$ relation where t is the total thickness of the Magnetic and non-magnetic layers. Because of such anisotropy, the magneto resistance too, is found to deepen on the direction of the magnetic field with respect to “easy” and “hard” axis of magnetization.



(a)



(b)

Fig. 2 (a) interfaces resistance Vs Temperature. (b)EDXS Chemical composition spectra for multilayer films of Co/Cu/Cu.

Co/Cu (110) STRUCTURES

The role in the magnetic switching behavior observed by Weber and his group et al for Co films on miscut surfaces is played by artificially induced reduced local symmetry at step sites, and also by the influence of atoms at these sites on the magnetic surface anisotropy. The Co/Cu (111) system provides further opportunity to study the role of morphology in determining magnetic behavior exhibits 3D growth mode seen for $Cu(001)$ substrate (Schneider et al., 1990). Studies at $300K$ using surface extended X-ray helps in observation of fine structure (E. R. Weber, 1963 and 1988). The two-fold symmetry of the $Co - Cu(110)$ surface plane contains three important axes; the axes of FCC, Co, as well as the (001) directions which are the symmetry axes for uniaxial anisotropies. Therefore the (110) orientation allows us to differentiate between the cubic and uniaxial anisotropy contributions due to different symmetry axes. In the Co thickness range $17 - 100$Å, it shows an unexpected suppression of the magneto crystalline anisotropy contribution below 50 ± 10Å Co. The magneto crystalline anisotropy contribution K_1 becomes vanishiningly small at Co thickness below$\approx .15Ml$. The magnetizations found to lie in plane for the studied range of $17 - 100$Å, Co, and strong in plane unixial anisotropy is found which has been a attributed to magnetoelasic effects at the Co/Cu substrate interface. The present magnetic measurements were carried out under Molecular Beam Epitaxy (MBE) condition with a base pressure of $1.4 \times 10^{-10} torr$ (Hillebrands.B, et al, 1996, Fassbrands.B, et al, 1995, Hope.S, etal, Mat.Res.Symp Vol.475p143). The single crystal $Cu(110)$ substrates were cleaned by $1kv$ Ar^+ ions and annealed to $(700 - 750k)$, untill Auger Electron Spectroscopy (AES) and reflection high electron energy diffraction (RHEED) measurement indicated a clean, well-ordered surface. The onset of ferromagnetism in this system occurs atdc: $3.45 \pm 1.17)ML$ and is indicative of the 3D growth mode in the Co/Cu (110) system. The details of the paramagnetic-ferromagnetic phase transition are discussed elsewhere. The measurements of a $3ML$ Co film grown on $Cu(110)$ are show in figure 3. The top and bottom panels shows $M - H$ loops obtained with the field applied paralleled to the [001] and $[1 - 10]$ direction respectively. The time elapsed after the end of the Co deposition is given in minutes underneath each loop. A square loop with unity remanence is observed a long the [001] direction five minutes after the end of the Co deposition, the $M - H$ loops are observed to evolve continuously in time until the [001] direction has become a magnetically hard axis after 60 minutes. Rotating the sample so that the field is now applied along the $[1 - 10]$ direction we observe an easy axis square loop with unity remanence a long this direction. Therefore, the magnetic easy axis has switched 90^o to favor the $[1 - 10]$ direction over a period of approximately one hour. The bottom panel shows that once the easy axis has switched, there is only a very small reduction in coercive field up to l10:00 minutes, after which the loops stop evolving and we find no further changes in the easy axis direction. Qualitatively equivalent behavior is observed for all Co thicknesses studied in the range$3Ml < d_{Co} < 37ML$. Although it is found initially that the time taken to switch easy axes remains constant at $\approx 9ML$, the same experiments are observed to show down by more than an order of magnitude as a function of the time the system has remained under MBE condition after bake out. We emphasize that this slowing down occurs even though there is no measurable change in the base pressure of the system $(1 \times 10^{-10}) torr$. This finding immediately rules out the processes of surface reconstruction and supports thermally driven Co segregation processes as the driving mechanism RIIEED indicates that the Co remains fcc up to $37ML$. Although AES detected no contamination within its resolution limit ($\approx 0.3ML$ residual gas from the MBE chamber is responsible for the magnetic switching, doping experiments on a $Co/Cu\,(110)$ system seems to be element specific, sensitive only to Co gas. This contrasts strongly with the behavior reported for the vicinal $Co/Cu\,(110)$ system studies by (Hope, Gu, Choi, & Bland, 1998; W. Weber et al., 1996).

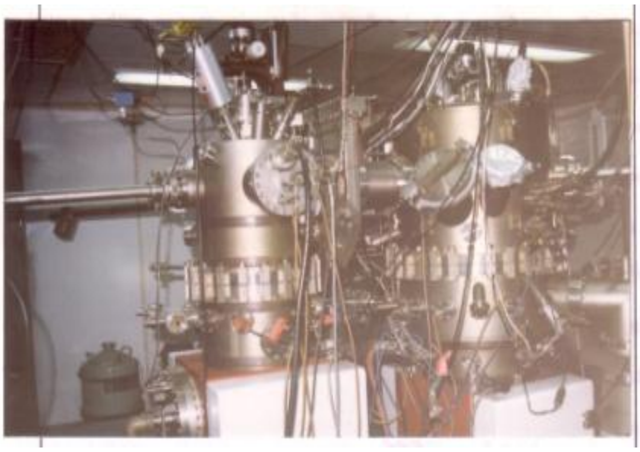


Fig. 3 MBE (Varian) systems as growth and AES for Surface and dept profiling during fabrication films.

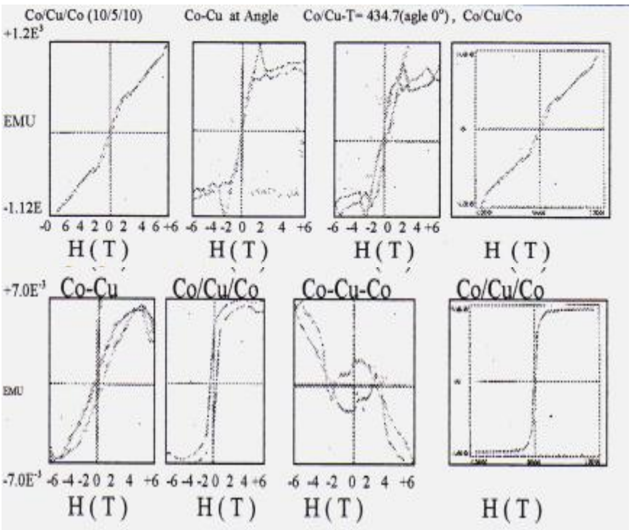


Fig.4 M-H loops for changing direction of applied magnetic field and different thickness

MAGNETIC MULTILAYERS AND INTERLAYER COUPLING

Successive ferromagnetic layers of nanometer-scale thickness separated by nonmagnetic spacer arrange themselves with their magnetization vectors either parallel ferromagnetic (FM) coupling or anti-parallel antiferromagnetism (AF) coupling to each other. The magnetic arrangement of the layers is an oscillatory function of the thickness and nature of the interfaces. Especially how these parameters affect the period of the oscillations and the inter layer coupling strength, as well as the specific connecting mechanism between the FM layer, are questions that have motivated recent research in this field. Moreover, for multi-layers with spacer thicknesses corresponding to an anti-parallel magnetic alignment, t he application of a strong magnetic field would rearrange the magnetization. Simultaneously, the electrical resistivity of the multilayer decreases and this change can range from a few percent up to anomalously large values giant Magneto resistance (GMR). Explanations for this effect have focused with different spin orientation. Moreover, the GMR effect has significant technological implications with potential applications in magnetic sensing and information's storage. Moreover, the comparisons between experiment and theory depend on the ability to accurately determine oscillation periods: this is a particular strength of the microscopic approach used here. In the case of good epitaxial growth the exact number of Monolayer's deposited is frequently monitored by measuring the oscillations in intensity of a reflection high energy electron diffraction (RHEED) beam diffracted from the surface while depositing the over layers. A beam diffracted from islands in the $n-1$ layer as well as from the uncovered n layer can made to interfere so as to reduce the RHEED intensity: the intensity returns to its former value when layer $n-1$ is complete and the interference vanishes. The evolution of islands into layers, as seen by the RHEFD beam during deposition, is preserved exactly. In the Co wedge and can be viewed by scanning the RHIEED beam along the wedge in the direction of increasing thickness, that is, the elapse deposition time. Using the SEM beam in a RHEED configuration and measuring the diffracted intensity as the SEM beam raster over the wedge region produces a RHEED image capture (spot) correspond to the most important source of the observed GMR appears to be spin-selective dissipative scattering in or near the interfaces between magnetic and spacer layers, or at the boundaries of granules. In the two-fluid model, the strong interface scattering is essentially transparent to one of the spin fluids, which is not affected by this scattering when layer magnetizations are parallel. For anti-parallel or randomly oriented layer magnetizations, mean free paths are reduced equally for both spin fluids, and the total conductivity is reduced. Since this happens for layered systems of consider able thickness, the electronic wave functions are well approximated by assuming semi-infinite geometry, and are not confined to individual material layers. In view of this, the Fuchs and Sondheimer (FS) confinement effect is probably not directly involved in the observed large magneto-resistance, although it must be taken into account with respect to the outer boundary (vacuum interface).For a-strip of given thickness the confinement effect produces the greatest reduction of conductivity for the largest value of mean free path (W. Weber et al., 1996). In the two-fluid model, this occurs for the favored spin component. It follows that the confinement effect actually reduces the magnitude of the GMR ratio, whose large observed values must arise from some more specific mechanism. While the relaxation time is characteristic of dissipative scattering effects that may be unrelated to the electronic structure of this material. Equation (5) implies that conductivity is dominated by the largest values of the mean free path. Thus, in examining the cause of enhanced magneto-resistance in particular materials theory must consider the largest possible values of the Fermi velocity, Systematic calculations of layer-dependent nonlocal conductivity were carried out for tri layer $Co/Cu/Co$ spin-valve structures (Butler & Zhang, 1991; Sondheimer, 1952), using Kubo theory without vertex corrections. The physical model is that of Cu layers of varying thickness embedded in Co. The layers have (111) orientation in a fcc lattice. Quasi particle lifetimes were parameterized, not computed from a first principles model. In this study, the methodology was verified by computing the layer-dependent conductivity of a free–electron gas, subject to a specified bulk relaxation time, and by comparing results with the analytical model of (Zhang & Butler, 1995)).similar test of both CIP and CPP conductivity were made for pure Cu and for both spin components of the current density of pureCo. It has been known for some time that the energy- band structure of Cu at the Fermi level is very similar to that of the majority-spin bands in magnetizedCo, but different from the minority-spin bands. This up (majority) implies qualitatively that spin-conduction electrons move freely between the two metals, while spin-down electrons are impeded by a potential mismatch. How this affects dissipative conductivity, which depends on scattering, has been discussed by Nesbit. Who computed the implied strong spin- selective scattering due to inter diffusion of atoms across a layer interface (Butler, Zhang, Nicholson, & MacLaren, 1995; Sondheimer, 1952). Strong spin asymmetry of scattering by impurities in transition-metal matrices is well experimentally and has been established experimentally and has been Considered to be a likely cause of enhance magneto resistance the first observation of GMR (Nesbet, 1998). Quantitative theoretical studies of residual resistivity have been carried out by (Baibich et al., 1988; Mertig, Zeller, & Dederichs, 1994) on Ni and ternary alloys. The meth used is, described in detail by(Vojta, Mertig, & Zeller, 1992).

EXPERIMENTAL

Surface reconstruction due to coverage of Co And $Co\ Si$ Island growth on Si (100). The initial stages of epitaxial growth of Co, Si_2 on silicon have been observed by several others (Honda, Fujimoto, & Nawate, 1996). Most experiments are performed on $Si(111)$ because of the more favorable growth condition. Even Co coverage of mono layer (ML) deposited on $Si(100)$ at 500^0C under UHV MBE conditions surfaces to induce a reconstruction of the surface. The reconstruction is based on the incorporation of atoms at solubility of $3.7x10^7\ Co\ cm^{-3}$ at$500^oC.$ The surface supersaturates instantaneously at MBE deposition rates and as a consequence, the reconstruction appears accompanied by surface strain at very low Co coverage aligned perpendicular to direction of the substrate dimmer rows and the growth rate during deposition decrease with decreasing substrates temperature. However, the density of growth reduced defects increases with decreasing temperature. The impact of the individual parameters in principal is required and the associated problems need to be solved in order to provide a background for the optimization process. Layer formation by MBE requires a high concentration of precipitates embedded within the matrix, since desired layer evolves from the precipitates.

CONCLUSIONS

Magnetic multi-layers have interesting possibilities both theoretically and experimental in Understandings spin dynamics (Mertig et al., 1994). It is crucial to have good epitaxial films. Present work represents our preliminary experiments on growth of crystalline magnetic film and normal metal layers of monolayer level. This opens up a new branch of study of spin injection and absorption for diagnostic and measurement of the electron transport through metallic nanostructure interest. The quantization of conductance in integral multiples of e^2/h is a noteworthy aspect. The conductance between left and right electrode depends on the relative orientation of magnetization between them. The examples are magnetic tunnel junction (Baibich et al., 1988). Spin dependent quantization, $2_e^2/h$ to e^2/h switching of the quantized conduction (H. Oshima and K. Miyano, (1998); Ono, Ooka, Miyajima, & Otani, 1999).

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