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Quantum-well based TMR effect in double-barrier magnetic tunnel junctions

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Double-barrier magnetic tunnel junction (DBMTJ) where the quantum well (QW) can be formed in ultrathin magnetic film sandwiched between two parallel barrier layers can be tuned by thickness and magnetic orientation of the middle layer. It is an ideal model to study the discrete QW energy level, QW states and QW tunneling magnetoresistance (QW-TMR). It is critical to develop kinds of novel spintronic devices based on QW-TMR and QW resonant tunneling diode. Thus, this topic has attracted much attention in magnetic research field.

QW states and QW resonant TMR predicted by *ab-initio* calculation was reported in our previous investigation.[1] The calculation of density of states shows that the QW states formed in majority Δ_1 band in middle Fe layer, which is confined by two MgO layers. The first principal calculation reveals the QW position as a function of Fe thickness, which is in good agreement with phase accumulation model (PMA) and shows free electron character of QW states. This work provides theoretical support for further study of QW resonant TMR in DBMTJ based MgO barrier and attracted much attention.[1] However, it is challengeable to fabricate high quality DBMTJ and the experimental results of QW are much weaker than theoretical prediction. Up to now, the phase coherence in QW states is only slightly observed in ultrathin layer with thickness of 1~2 nm.[2] In this case, it is impossible to modulate the Fermi level energy E_F by making a direct electrical connection with the middle QW layer. The decoherence process can be introduced by interface roughness or inelastic scattering in the QW and at the interface. To prevent the decoherence and realize the resonant tunneling in wide QW width, it is necessary to further optimize the structure and material for DBMTJ.

Recently, we developed the epitaxial DBMTJ with core structure Fe(001)/MgAlOx/Fe(d)/MgAlOx/Fe by MBE system.[3] The thickness of middle Fe layer is 6.3 nm, 7.5nm, and 12.6 nm, respectively. The oscillations of conductance as a function of bias have been observed in all the samples. The number of oscillations increases with increasing thickness of Fe and the position of peaks are in good agreement with *ab-initio* calculation and PAM results, which confirms that the oscillations originate from the QW states in middle Fe layer. The long range phase coherence in such wide QW is attributed to the perfect Fe/MgAlOx interface and high quality middle Fe film. The small lattice mismatch of Fe and $MgAlO_x$ induce small strain and few dislocations at the interface, which result in a small distribution of phase shift at the interface and enhance the QW resonant tunneling effect. Remarkably, up to ten separated QW resonance states were observed on DBMTJs with a 12 nm thick Fe QW from low to room temperature.[3]

The above theoretical and experimental study provides important reference for further study and exploiting QW states and QW resonant TMR and achieving higher TMR ratio. This will promote the development of spintronic devices and applications. Further research about this project is in process.

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