Investigation on the micromagnetic interactions of lower dimensional systems

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ABSTRACT

In these internet days, magnetism has become the inseparable component of mankind and its utilization in modern technology finds no boundary. It ranges from high density storage devices to READ/WRITE head in recording media, sensors and other communication devices and many more innovative reaches. The demand for magnetic materials for different applications, have paved way for the development of many new magnetic devices with varied geometries and sizes. These devices are made by nurturing the unattended features of the magnetic materials, like spin quantization and polarization, which is useful for transportation as in spintronics device, giant magneto resistance (GMR) device and spin transfer torque (STT) devices. Magnetic materials have become controllable on the nanometer scale hence; fabricating fine structures such as thin films, monolayer, bilayer and multilayers and even nano dots have become possible. The magnetic systems comprising of these structures exhibit a wide range of fascinating phenomena such as low dimensional magnetism, Giant Magnetoresistance (GMR), magnetic switching, magnetic tunneling etc. Magnetic multilayer with nanometer spacing is among the first metallic quantum structures to be incorporated into electronic devices such as reading heads for hard disks. As a result, a class of magnetic/non-magnetic multilayers termed ‘spin valves’ has been introduced into magnetic storage devices.

The study about these low dimensional magnetic systems is one of the central issues in the physics of mesoscopic magnetic systems and it is a true variant of electronics in which the electron spin is used rather than the electron’s charge.

The discovery in the field of spintronics is mainly caused by the interaction of flowing electrons with the background magnetization inside a ferromagnet. As more and more magnetic devices keep emerging with miniaturized size, the knowledge about the low dimensional interaction in them needs to be investigated. Most of the theoretical and experimental studies done on these lower dimensional magnetic systems reveal lots of interesting fact. It is found that the unique properties exhibited by them are completely contrasted to their bulk material. In general, most of the lower dimensional magnetic systems, are either single layered, as in thin film geometry or multilayered, as in spin valve pillar which are devised as sensors, READ/WRITE heads and magnetic junction tunneling diodes. These magnetic structures exhibit exclusively different characteristics namely, high coercivity, high magnetization and hysteresis and intriguing nonlinear wave phenomenon, such as magnetization switching or reversal, quasi periodicity, phase locking and chaos.

The spin dynamics of the magnetic materials in bulk systems has already been studied by many researchers in the past and it is understood that the system inherently has nonlinear interactions, under suitable conditions; it was observed that the localized energy excitations exhibit soliton behaviour. Thus we were motivated to extend the similar investigations on lower dimensional magnetic systems as well to understand the spin dynamics, the evolution of magnetization dynamics and the various energy interactions. The knowledge of which may be used in the realization of advanced devices.

Our study basically is to understand the dynamics and evolution of spin magnetization in low dimensional magnetic system. The systems we have considered for investigation are the common magnetic multilayer in the form of spin valve pillar or a magnetic tunneling junction. We have also done our investigation an alternating cubic spinel ferromagnetic Heisenberg structure which has interlayer exchange energy interactions due to the spin-spin coupling and additional spin-orbit coupling namely biquadratic and Dzyaloshinsky–Moriya interactions. A $Co_2FeAl_{0.5}Si_{0.5}$ based Heusler alloy materials which has magnetic properties are layered as spin valve was also investigated.

We have investigated the nature of interaction that prevails during the propagation of an electromagnetic wave through these magnetic layers. The dynamics of the evolution magnetization of this interaction between electric vector of the wave and the magnetization vector of the ferromagnetic medium of the layer was of particular interest of our investigation. We have modeled the magnetization of the system using Landau-Lifshitz-Gilbert-Slonczewski equation, allowed it to couple with the Maxwell's equation for electromagnetic wave in ferromagnetic medium. This was modeled by nonlinear evolution of equation.

Solving the nonlinear equation as such is a challenging task and many a times suitable switching technique has to be selected to modify it. This nonlinear equation can be solved for exact solutions using mathematical techniques such as reductive perturbation method, Holstein Primakoff method, and Inverse Scattering Transformation. The complicated equations reduced to the most celebrated kdV equations or NLS equations which revealed the localized solitonic nature of excitations. These solitons arises due to the precise balance between the effects of nonlinearity and dispersion. These solitons have a constant velocity and they maintain their shape even after collision with another soliton. The spin polarized current transferred through a magnetic body can switch its magnetic moment without applying an external magnetic field.

We have studied the interaction of magnetic field vector with the localized magnetization of the medium of a spin valve during the propagation of electromagnetic wave in an array of spin valve pillar. The Landau-Lifshitz-Gilbert equation for magnetization of the ferromagnetic layer, by including the spin transfer torque term introduced by Slonwencki, along with the conventional precession and damping term is used for describing the evolution of magnetetization . This equation is coupled with the Maxwell's equation of electromagnetic waves for ferromagnetic medium and using the reductive perturbation method, it was reduced down to KdV equation. The solutions for this equation admit localized excitations, known as solitons.

It was also intended to observe the Magnetization switching and its dynamics in spin valve nanopillar, induced by spin transfer torque in the presence of a periodic applied field. Under steady state conditions the switching of magnetization occurs in the system, above a threshold current density value J_c .A general expression for the critical current density is derived and it is shown that this further reduces when there is magnetic interface anisotropy present in the free layer of the spin valve. We also found that the behaviour of the free layer magnetization vector in a periodically varying applied magnetic field is chaotic, in the presence of a constant DC magnetic field and spin current. Further it is found that in the presence of a nonzero interfacial anisotropy, chaotic behaviour is observed even at much smaller values of the spin current and DC applied field.

Investigation on the elementary excitations in alternating cubic ferromagnetic material multilayer is done, by taking the Hamiltonian of the system, along with the different types of interactions prevailing within it, namely exchange interactions, external magnetic field, anisotropic field, symmetric exchange (Dzyaloshinsky–Moriya coupling) and biquadratic coupling, Using Holstein-Primakoff transformation to the spin operators of the Hamiltonian, and coupling with Glaubert coherent state method, equations in the form of nonlinear Schrodinger equation is obtained using inverse scattering method, we have constructed the solutions. These solutions exhibit soliton-like magnon localization in the alternating ferromagnetic Heisenberg chain is possible even in the presence of DM interaction and biquadratic interaction under specific parametric choices.