

# **SPIN-POLARIZED CURRENT DRIVEN MAGNETIZATION DYNAMICS AND APPLICATIONS IN SPIN VALVE PILLARS**

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*by*

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# ABSTRACT

Moore's law, the holy grail of current semiconductor industry, anticipates an approximate doubling of transistors on integrated circuits every two years. This downscaling of IC size with concomitant increase in computational power seemed saturated about a decade ago, due to the individual transistor size approaching the size of an atom. This modifies the laws of semiconductor physics as we know it, bringing in tangible quantum mechanical effects. One of the road ahead for the semiconductor industry is to take into consideration the *spin* of the electron along with its electric charge in designing novel, energy-efficient and non-volatile memory devices and much more. The contemporary area of technology aimed at accomplishing all these came to be known as *spintronics*.

In this thesis we approach the device physics of some of the highly sought after spintronic devices using a *dynamical systems* approach, which models these devices at a semi-classical level and study them using a dynamical equation (The Landau-Lifshitz-Gilbert-Slonczewski equation). We specifically focus on the current driven dynamics in the spin valve pillar devices, which are the basic GMR cells to be transformed into a memory cell, a logic gate, or a nano-oscillator. We derive significant results on two fronts which are potential interests to both academia and industry— magneto-logic gates, and spin-torque nano-oscillators.

We propose model magneto-logic NOR and NAND gates using a spin valve pillar, wherein the logical operation is induced by spin-polarized currents which also form the logical inputs. The operation is facilitated by the simultaneous presence of a constant controlling magnetic field. The same spin-valve assembly can also be used as a magnetic memory unit. We identify regions in the parameter space of the system where the logical operations can be effectively performed. The proposed gates retain the non-volatility of a magnetic random access memory (MRAM). We verify the functioning of the gate by numerically simulating its dynamics, governed by the appropriate Landau-Lifshitz-Gilbert equation with the spin-transfer torque term. The flipping time for the

logical states is estimated to be within nano seconds. Further we show that current induced magneto-logic gates like AND, OR and NOT can be designed with the simple architecture involving a single nano spin-valve pillar, as an extension of our work on spin-torque-driven magneto-logic universal gates, NAND and NOR.

As another possible application, we propose and mathematically model a system of two coupled spin-torque nano-oscillators (STNO), one driver and another response, and demonstrate the synchronization of the response system to the frequency of the driver system. To this end we use a high-speed operational amplifier in the form of a voltage follower, which essentially isolates the drive system from the response system. We find the occurrence of 1 : 1 as well as 2 : 1 synchronization in the system, wherein the oscillators show limit cycle dynamics. An increase in power output is noticed when the two oscillators are locked in 1 : 1 synchronization. Moreover in the crossover region between these two synchronization dynamics we show the existence of chaotic dynamics in the slave system. The coupled dynamics under periodic forcing, using a small ac input current in addition to that of the dc part, is also studied. The slave oscillator is seen to retain its qualitative identity in the parameter space in spite of being fed in, at times, a chaotic signal. Such electrically coupled STNOs will be highly useful in fabricating commercial spin-valve oscillators with high power output, when integrated with other spintronic devices.