



A Low-Dimensional Layout Of Magnetic Units As Nano-Systems Of Combinatorial Logic: Numerical Simulations

Dr. Rakesh Kumar

Assistant Professor, Department of Physics,

Maa Bageshwari College Korma Gaya, Magadh university Bodh Gaya, Bihar. India.

Corresponding Author - Dr. Rakesh Kumar

DOI - 10.5281/zenodo.17120583

Abstract:

Nanotechnology has opened numerous ways for physically realizing very sophisticated nanodevices that can be fabricated exclusively using molecular engineering methods. However, the synthesis procedures that lead to the production of nanodevices are usually complicated and time consuming. For this reason, the destination materials should be well designed. Therefore, numerical simulations can be invaluable. In this work, we present numerical simulations of the magnetic behaviour of magnetic units shaped into nanometric strips as a low dimensional layout that can be used as nano-systems of combinatorial logic. We showed that magnetic layouts that contain fewer than 16 magnetic units can take on a specific configuration as a response to the input magnetic field. Such configuration can be treated as an output binary word. The layouts that contained various numbers of magnetic units showed different switching characteristics (utterly different order of inverting of strips' magnetic moments), thus creating numerous combinations of the output binary words in response to the analog magnetic signal. The number of possible output binary words can be increased even more by adding parameters—the system's initial magnetic configuration. The physical realization of the model presented here can be used as a very simple and yet effective encryption device that is based on nanometric arrays of magnetic units rather than an integrated circuit. The same information, provided by the proposed system, can be utilized for the construction of a nano-sensor for measuring of magnetic field with the possibility of checking also the history of magnetization.

Keywords: *Magnetic Particles, Numerical Simulations; Combinatorial Logic Systems, Nanoelectronics, Macrospins, Micromagnetic Simulation, Multistage Switching.*

Introduction:

Molecular engineering [1,2], one of the most important tools in nanotechnology, enables to broke the frontiers in the modern technology [3]. Nanotechnology can be considered as some kind of “reversed physics”. For classical physics, we start from the “solving” the materials to find all the properties they have, their structure, and all of the physical laws that apply to them. Once we have these, we can consider some

possible applications for the investigated matter. In the nanotechnological approach, we start from considering the most prospective application for some unknown material after which we can try to find some physical and chemical properties that enable it to be used in a manner being considered. In the next step, the molecular structure should be designed in such a way as to imply assumed properties to the resulting material. Next, we should design and

execute the synthesis. Having the synthesized material, the classical physical methods can be used to verify the assumptions. The approach presented above is quite effective, as far as synthesizing the materials for practical applications is concerned. However, It is not an easy process to do that. Both synthesizing a material with assumed properties, as well as designing the correct molecular structure, is extremely difficult in most cases. Considering the latter process, numerical simulations can help significantly. Let us consider the layout of regular magnetic units. When we assume suitably small dimensions of the units, the fabrication of a super-dense memory storage, magnetic Nano sensors, molecular neural networks or combinational logic nanocircuit becomes possible [4,5,6,7,8,]. Importantly, the last-mentioned application seems to be promising because such systems can be used in many emerging technologies, such as encryption, encoding, or data compression. The system can be theoretically fabricated using electrochemical methods combined with other nanotechnology tools, which can be selected depending on the assumed geometry, which should be thoroughly thought out because the magnetic behaviour of low-dimensional nano layouts is not always obvious. Such a system's magnetic response to the magnetic field that is applied depends strongly on the number of magnetic units in the whole system. This factor is

crucial because it enables the binary encoding of the analogy input signal. We describe the assumed operating of the nanometric combinational logic system further in the text.

Materials and Methods:

In this study, we considered the properties of a chain layout of magnetic units regarding the number of magnetic particles [16,17]. The model system is composed of magnetic rectangular strips (350 nm wide, 5000 nm long, and 30 nm thick), which were laid in a regular linear layout as is depicted in Figure 1. The distance between the magnetic strips was 100 nm. The material of strips was permalloy Ni₈₀Fe₂₀ with saturation magnetization of 890 kA/m and exchange stiffness parameter of Considering the assumed use of the model as a combinational logic nano circuit, we paid special attention to the switching properties of the material. As we show below, based on the numerical simulations, the magnetic response of the chain of magnetic particles on the applied magnetic field strongly depended on the number of magnets (magnetic units) in the chain and was very irregular. We studied this irregularity with regard to using it in the binary encoding of an analogy signal. The simulations that are presented are part of the molecular design of actual nanoelectronics systems and seem to be crucial in this.

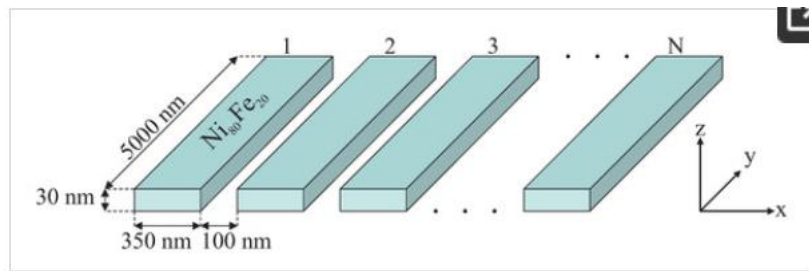


Figure 1. A schematic illustration of the model that was used to approximate the finite layout of the magnetic units.

The general magnetic behaviour of the system presented in Figure 1 was analysed in detail in our previous work. The present paper is a continuation of our earlier investigations. Here, we exploit and present the applicative potential of the system in nanoelectronics. For this reason, we describe the system's switching properties using various numbers of magnetic units in the layout and focus on the features that are important for the binary coding of an analog input signal (the magnetic field that is applied). A detailed description of the model and details of the simulations were described in our earlier article. In short, we assumed that a magnetic field is applied to the chains in the Y direction (parallel to the long axes of the magnetic units). To find the equilibrium configuration for each field value, we minimized the magnetic energy using MuMax software. As far as the simulations are concerned, we focused on the following numbers of magnets: and infinite. The most promising ones were the numbers fewer than, while the higher numbers were treated as references for the discussion. Obviously, we also investigated other numbers of magnets in the layout. However, here, we present only the most interesting and most important cases. It is crucial to highlight that an even or odd

number of magnets behaved differently when the number of magnets was close because of the different symmetry with regards to the central point.

The model that is presented is the first approach to an actual device: the layout of permanent magnetic units fabricated at a nanometric scale. Such a system can theoretically be done using a few methods. The first and most obvious method is electrodeposition using a nanolithographic shutter [23,24,25,26]. Considering the current state of the technology, fabricating the geometry presented in Figure 1 does not seem to be a problem. When we consider smaller systems, however, another method should be used. In these cases, rather than a nanolithographic shutter, an ordered porous matrix that deposited on an electrode can be used during the electrodeposition. These methods result in systems of ordered cylinders rather than strips, but after cutting of the properly oriented thin strip using a focused ion beam (FIB), the final geometry would be similar to the one presented here. As a shutter, the porous anodic alumina matrix] can be used to fabricate various systems with strips ranging from 300 nm down to 10 nm wide. Even smaller units can be obtained by using inside ordered porous silica matrices [30], which can be prepared

in the form of vertically aligned systems of pores [31,32]. In this case, we can even go as low as 2 nm wide.

It seems to be clear that the physical implementation of a system using magnetic strips is feasible. What is more, the geometry of these systems can be tuned. For this reason, simulations of the magnetic behavior of low-dimensional magnetic layouts seem to be justified for designing and fabricating the nanometric system that are to be used in nanoelectronics.

Results and Discussion:

The dependence of a magnet's behavior on the number of magnets in the layout of a chain is presented in Figure 2. As a starting point, we assumed the antiferromagnetic (AF) arrangement of the magnets. However, after the magnetic field was saturated, the system's configuration was ferromagnetic (FM) and this was the starting point for decreasing of the magnetic field.

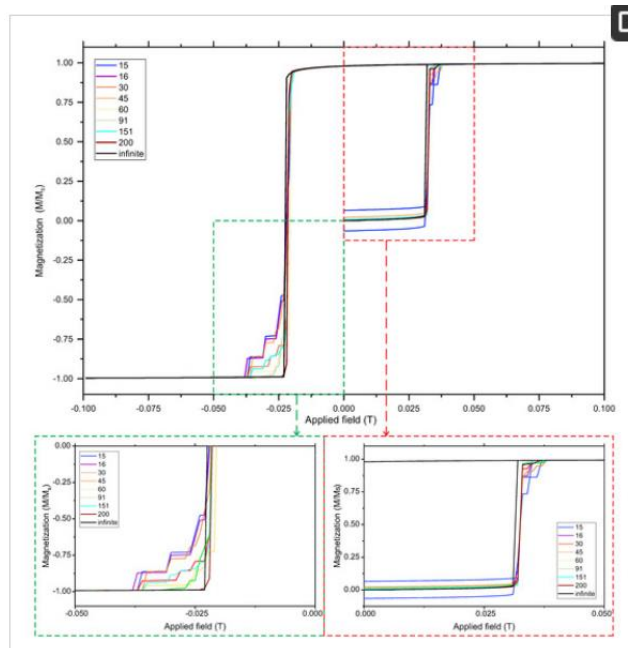


Figure showing Hysteresis loops for the system with the selected number of magnetic units that were used along with an enlarged view. The second part of the hysteresis loop (field from minimum to maximum) was omitted for the clarity of the picture.

Looking at the plot (Figure 2, one can easily observe that the finitude of the number of magnets in the system strongly influenced the existence of the states that are intermediate between AF and FM, and FM and a reversed ferromagnetic (revFM) state.

In this case, there are two distinguished magnets in the system that require attention: the first and the last magnets. What is more, the number of intermediate states and their configuration was strongly dependent on the number of magnets in the chain, the parity of the number of strips in the chain and the initial configuration of the system (AF or FM). This fact is extremely important for the practical application of an actual system as a combinatorial logic element. It can clearly be seen that the steps (intermediate states) become practically invisible for 200

magnetic strips in the chain. Such a chain behaves similar to an infinite chain. In the case of an infinite chain, in turn, the intermediate states do not exist. The reason for this is that none of the magnets is distinguished and the only possibility for reorienting the magnetic field is to flip all of the strips simultaneously. For this reason, only low-dimensional chains of magnetic strips can be considered as a part of the nanoelectronics systems for encoding, encryption and data compression.

Conclusions:

In this study we have presented a numerical model of a low-dimensional layout of magnets that can theoretically be used as a nanoelectronics device to encode an analog signal (magnetic) into a system of binary digits (digital output). The proposed device has a great applicative potential for encryption tasks or data compression. Our research showed that the number of magnets in the layout is crucial for the operation of the proposed device; a relatively small number of units—200—can approximate a continuous system, which is completely useful in the proposed application (however, some other application possibilities can also be found). The systems that contained up to 16 magnets were the most promising. The layouts that contained various numbers of magnets behaved in different ways, which created numerous combinations of the output binary words in response to the analog magnetic signal. The number of possible output binary words can be increased even more by the additional parameter—the system's initial magnetic configuration. All of this makes the model

magnetic system very interesting as far as its potential application in nanoelectronics is concerned, especially as nanodevices for encryption and data compression or nanosensors of magnetic field. The next logical step of the research seems to be to attempt to synthesize an actual system and to determine whether the behaviour of such a physical layout is well represented by the simulations that are presented here, which is definitely worth doing.

References:

1. Drexler, K.E. Molecular engineering: An approach to the development of general capabilities for molecular manipulation. *Proc. Natl. Acad. Sci. USA* 1981, 78, 5275–5278. [Google Scholar] [CrossRef]
2. Tong, L.; Goulet, M.A.; Tabor, D.P.; Kerr, E.F.; De Porcellinis, D.; Fell, E.M.; Aspuru-Guzik, A.; Gordon, R.G.; Aziz, M.J. Molecular engineering of an alkaline naphthoquinone flow battery. *ACS Energy Lett.* 2019, 4, 1880–1887. [Google Scholar] [CrossRef]
3. Corriu, R.; Mehdi, A.; Rey  , C. Nanoporous materials: A good opportunity for nanosciences. *J. Organomet. Chem.* 2004, 689, 4437–4450. [Google Scholar] [CrossRef]
4. Matko, V.; Šafari  , R. Major improvements of quartz crystal pulling sensitivity and linearity using series reactance. *Sensors* 2009, 9, 8263–8270
5. Matko, V.; Milanovi  , M. High resolution switching mode

- inductance-to-frequency converter with temperature compensation. *Sensors* 2014, 14, 19242–19259.
6. Yang, S.; Tan, M.; Yu, T.; Li, X.; Wang, X.; Zhang, J. Hybrid Reduced Graphene Oxide with Special Magnetoresistance for Wireless Magnetic Field Sensor. *Nano-Micro Lett.* 2020, 12, 1–14
 7. Zhang, Y.; Yuan, H.Y.; Wang, X.S.; Wang, X.R. Breaking the current density threshold in spin-orbit-torque magnetic random access memory. *Phys. Rev. B* 2018, 97.
 8. Lin, G.T.; Zhuang, H.L.; Luo, X.; Liu, B.J.; Chen, F.C.; Yan, J.; Sun, Y.; Zhou, J.; Lu, W.J.; Tong, P.; et al. Tricritical behavior of the two-dimensional intrinsically ferromagnetic semiconductor CrGeTe₃. *Phys. Rev. B* 2017, 95.
 9. Huang, B.; Clark, G.; Navarro-Moratalla, E.; Klein, D.R.; Cheng, R.; Seyler, K.L.; Zhong, D.; Schmidgall, E.; McGuire, M.A.; Cobden, D.H.; et al. Layer-dependent ferromagnetism in a van der Waals crystal down to the monolayer limit. *Nature* 2017, 546, 270–273.
 10. Oh, S.; Jang, B.J.; Chae, H. Sensitivity Enhancement of a Vertical-Type CMOS Hall Device for a Magnetic Sensor. *J. Electromagn. Eng. Sci.* 2018, 18, 35–40.
 11. Cowburn, R.P. Room Temperature Magnetic Quantum Cellular Automata. *Science* 2000, 287, 1466–1468. [Google Scholar] [CrossRef]
 12. Laskowski, Ł.; Laskowska, M.; Jelonkiewicz, J.; Boullanger, A. Molecular approach to hopfield neural network. In *International Conference on Artificial Intelligence and Soft Computing*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 72–78.
 13. Laskowski, Ł.; Laskowska, M.; Vila, N.; Schabikowski, M.; Walcarius, A. Mesoporous silica-based materials for electronics-oriented applications. *Molecules* 2019, 24, 2395.
 14. Datta, M.; Landolt, D. Fundamental aspects and applications of electrochemical microfabrication. *Electrochim. Acta* 2000, 45, 2535–2558.
 15. Salman, A.; Sharif, R.; Javed, K.; Shahzadi, S.; Kubra, K.T.; Butt, A.; Saeed, S.; Arshad, H.; Parajuli, S.; Feng, J. Controlled electrochemical synthesis and magnetic characterization of permalloy nanotubes. *J. Alloys Compd.* 2020, 836, 155434.