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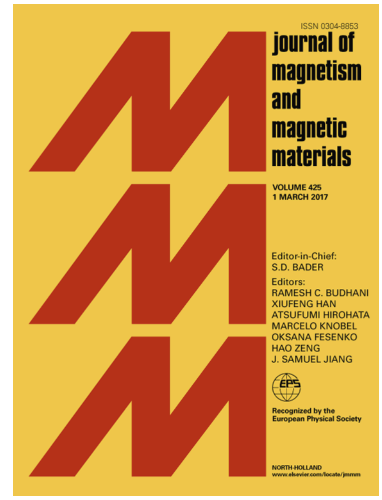


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# Unusual behavior of the magnetization reversal in soft/hard multisegmented nanowires

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The magnetization reversal mechanisms in soft/hard multisegmented nanowires have been investigated using numerical simulations. In most of the studied systems the magnetization reversal process starts at the ends. However in short soft/hard/soft nanowires, the magnetization reversal process starts at the center of the wire, generating an unusual behavior of the coercivity as a function of the length.

## I. INTRODUCTION

During the last decades, the study of magnetic nanowires (NW) has attracted strong attention because of their potential for applications in diverse areas such as binary information, high-density and high-speed data storage [1, 2], and biology [3]. Different lithographic techniques can be used to grow magnetic NWs, however they are usually very expensive and time consuming. An alternative is the use of chemical template-based methods combined with high-yield electrochemical deposition techniques. A widespread example are anodic aluminum oxide (AAO) membranes, that allow a precise control of the geometrical features, such as nanopore diameter, length, and periodicity, by simply changing the anodization conditions [4–6]. Hence, several studies concerning single-element magnetic NW arrays of Ni, Co, Fe, and their alloys can be found in the literature [7–14].

Nanowires are usually very long, with an aspect ratio (length/diameter) larger than 10 that allows such structures to exhibit a significant shape anisotropy. Because of this, a single NW exhibits two lower energy states in which most of the magnetic moments are parallel to the wire axis, with square hysteresis loops characteristics of this bistable behavior [15]. However, in an array, interelement interactions and its distributions generate more complex reversal processes with non-square hysteresis cycles [16, 17].

Using similar techniques to those previously describes, it is possible to produce multisegmented nanowires, that is, wires composed by layers of different materials [18]. For example, Kuo Qi *et al.* [19] prepared NiCoCu/Cu multisegmented nanowires using electrodeposition techniques and dc current pulses. Almasi-Kashi *et al.* [20] were able to control the thickness of each segmentd by varying the number of ac-pulses in each layer of Fe/Cu nanowires. Tang *et al.* [21] studied CoNi/Cu multisegmented nanowires and observe that the interaction among magnetic segments defines the magnetization reversal. This was confirmed in a recent paper by Rando *et al.* [22], who studied the reversal modes in arrays of long multisegmented Ni/Cu wires. Finally, Pereira *et al.* [23] introduced a new soft/hard nanostructure based on multisegmented CoNi nanowire arrays.

An interesting system is formed by wires with soft and hard segments, since in such structures coercivity is usually determined by the hard phase while the remanence is originated in the soft phase [24–27], generating a mix of properties that can be tailored with the adequate election of materials. An example is shown in a paper by Forster *et al.* [28], who made micromagnetic calculations on magnetic wires composed of two parts, a soft magnetic part and hard magnetic part, showed that the domain wall velocity increases with increasing wire diameter and decreasing damping constant.

Agramunt-Puig *et al.* [29] used a simple but powerful model to study the collective magnetic response of large arrays of segmented nanowires comprising two magnetic segments of different coercivity separated by a non-magnetic spacer. The authors showed that the geometry can be optimize to attain antiparallel or parallel magnetic alignment, as required in magnetic sensors based on the GMR effect and other applications. A similar system was addressed by Allende *et al.* [30] who investigated the effect of the dipolar magnetic interaction between magnetic layers mediated by non-magnetic ones in segmented nanowires. The dipolar interaction generates two different reversal modes, according to its strength; an independent route, in which the segments reverse simultaneously, and a dependent one, when the segments are strongly coupled. This mode exhibits larger coercivities as compared with the ones that show parallel reversal mode and could be useful for the creation of multistable systems. Gapin *et al.* [31] proposed the use of soft/hard composite nanowire arrays of Ni/CoPt for patterned media, and S. M. Hamidi *et al.* [27] synthesized Ni, Co and Ni/Co multisegmented nanowires from a combined technique of AAO template and electrodeposition method, and showed that the multisegmented Ni/Co nanowires can be used as efficient magnetic field sensor.

The systems mentioned above have a strong shape anisotropy due to their length, which defines their magnetic behavior. However, the study of wires of reduced length has been less frequent, even more if they are formed by alternate segments of soft and hard materials. For this reason, in this work we focus on short wires

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