Extraordinary magnetoresistance in a 2-terminal structure

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State-of-the-art fault current limiters are based on active components or inductors, and are large and expensive devices. Here, we propose a new passive and miniaturized magnetoresistance-based system [1] strongly reducing device size and cost. The extraordinary magnetoresistance (EMR) effect was chosen as it exhibits the largest resistance ratio among the known magnetoresistive (MR) phenomena, reaching values up to 10^7 % [2].

Many works have studied EMR in high-mobility materials (like semiconductors [3], graphene [4] and heterostructures [5]) mainly for magnetic field sensing [2, 5]. For current limiter applications, only 2-terminal geometries are applicable. Through 2D finite element simulations (COMSOL), we have studied several geometry and material parameter combinations to understand if and how EMR-based current limiters can be realized. For instance, we have designed different planar shapes and sizes for the electrodes (such as van der Pauw disk [3], multibranch geometry [2], bar type geometry [5] or stripes). For 2-terminal systems, our simulations show that the EMR ratio reaches its largest value in simple sandwich designs, that maximize the resistance variation between current paths where the electrons cross the metal-semiconductor interface tangentially and normally, respectively. Comparing the EMR ratio values reported in the literature [2, 3, 5] with those resulting from our simulations, we suppose that the higher EMR values displayed by 4-terminal systems arise from a combination of Hall and EMR effects. 2-terminal systems, where the Hall effect is absent, exhibit instead lower EMR ratios.

Simulations show that EMR saturates with lateral extension of such 2-terminal systems. This EMR saturation varies as a function of electron mobility and out-of-plane magnetic field according to the following empirical relation: $EMR = 19.1(\mu B)^2$. This is in agreement with previous works [3]. It shows that it is possible to reach high EMR values of about 2000 % at a magnetic field of 1 T when the semiconductor materials mobility is around 10^5 $cm^2/(Vs)$. Such values are very promising for current limiter components. This behavior can also be found with a simple 2-channel model which describes 2-terminal systems, where electrons follow the least resistive path. It fits to the simulation data and gives $EMR = 8480l/(0.29+l)$, with l being the lateral extension of our system.

In summary, this work investigates a new passive and compact current limiter device concept based on the EMR effect. With proper mobility and good interfaces, an EMR ratio as high as 2000% can be achieved in a 2-terminal system, which could make this technology suitable to replace state-of-the-art fault current limiter components.

References

[1] P. Kopejtko, EP Patent EP3 961 925A1 (2022)
[2] T. H. Hewett and F. V. Kusmartsev, *Physical Review B*, **82** (2010) 21, 212404
[3] S. A. Solin et al., *Science*, **289** (2000) 5484, 1530-1532
[4] S. Pisana et al., *Nano Letters*, **10** (2010) 1, 341–346
[5] J. Sun and J. Kosel, *Materials*, **6** (2013) 2, 500–516