Comment on "Experimental Evidence for Sign Reversal of the Hall Coefficient in Three-Dimensional Metamaterials"

Kern *et al.* [1] claim the observation of a sign reversal of the Hall coefficient as a three-dimensional metamaterial effect. We point out that in Kern's structure the sign reversal happens already in the individual building blocks of their crystal, which makes its identification as a metamaterial effect questionable. However, the understanding of metamaterial effects might be different for different systems and seems to lack a strict definition. As an example, in photonic crystals the periodicity of the host metamaterial and the interaction between the elementary building blocks is decisive, while this is not the case in Kern's structure. Hence, a clarification for the general reader is necessary.

Depending on design parameters, in particular the separation parameter d, Kern *et al.* observed a systematic change of sign of the Hall coefficient upon varying d from positive ($d = 4\ \mu$m) to negative ($d = -22\ \mu$m) values. The key aspect in this context is the interconnection of the tori that are assembled in order to create a regular macroscopic three-dimensional structure. Figure 1 of the Letter [1] makes clear that all tori are connected in the same manner, either using connections just in the interior of the tori or just at the exterior of the tori. This aspect has been pointed out most clearly in the insets of Fig. 3(a) of the Letter, where a negative separation parameter $d = -22\ \mu$m corresponds to a chainlike arrangement, which requires interconnections at the interior of the tori, while a positive $d = 4\ \mu$m requires connections at the exterior of the tori.

From the topological point of view, we assert that the individual tori are equivalent to the ringlike structure, which has been investigated by Mani *et al.* [2] in the quantum Hall regime. It is a so-called anti-Hall bar structure that is embedded in a Hall bar and has been created in order to approach Laughlin's cylinder [3]. Mani *et al.* demonstrated experimentally that there appear simultaneous independent Hall voltages at the inner (anti-Hall bar) and outer boundary (Hall bar), depending just on the individual currents that have been injected simultaneously to the inner and outer edge by two independent floating current sources. By using a network model for magnetotransport in the quantum Hall regime, Oswald *et al.* [4,5] have shown that the observed experimental behavior can be modeled in agreement with the experiments. In Fig. 3 of Ref. [5] it is explicitly demonstrated that interchanging the current supply from the outer to the inner edge, while maintaining the current direction and the order of the pick-up contacts for the Hall voltage, produces a sign reversal of the Hall voltage.

The same happens within each of the interconnected tori if the interconnections move gradually from the exterior to the interior and the design of the metamaterial provides a clever way to add up the individual interior Hall voltages of the tori and carry the total Hall voltage to the outside boundary of the complete structure.

This becomes also clear if one looks at Fig. 4(b) of the Letter [1], where sign reversal is demonstrated considering a single torus. One might cut a single torus out of the whole 3D crystal and create contacts like those shown in Fig. 4(b) of Ref. [1]. The result of a Hall experiment would be that we get sign reversal if using connections at the inner boundaries. Consequently, the assembly of many tori into a 3D crystal has nothing to do with sign reversal itself. Since the authors do not rule out a sign reversed anti-Hall bar voltage to appear for the individual tori, the basic effect is the same as demonstrated by Mani [2,4,5]. In this context Mani's experiments go even beyond those of Kern *et al.*, because he additionally demonstrates that it can even generate both signs of the Hall voltage at the same time if supplying two independent currents to the inner and outer boundaries simultaneously.

The importance of the study by Kern *et al.* in context with the study of Mani *et al.* is also that it proves a universal behavior existing from the pure classical transport regime until deep into the quantum Hall effect regime. Additionally, this effect has been successfully simulated independently by a purely classical commercial software package (COMSOL Multiphysics) and by a network model for magnetotransport that covers the transport regime ranging from semiclassical magnetotransport to transport in the quantum Hall regime that is dominated by many particle interactions as most recently demonstrated [6].

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