Topology-Driven Design of Bianisotropic Metasurfaces Using Knotted Particles

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Abstract – Metasurfaces usually comprise unit cells based on metal strips or slots combined with dielectrics on a periodic lattice. Such designs have many advantages - they are easy to fabricate and in many cases can be modeled using simple circuit models to predict their response to impinging fields. However, current simulation and fabrication techniques, combined with the extensive analytical and semianalytical modeling techniques utilized in metamaterial research, allow us to exploit a broader range of geometries.

One intriguing class of structures are toroidal knots. Knotted wires were shown to have unique scattering and radiation properties. Due to their inherent chirality, they exhibit strongly asymmetric radiation and nearly optimal cross-polarization components. They are characterized by two indices, p, q - the number of revolutions the wire experiences around each center (torus center, and torus cross-section), as shown in Fig. 1. When arranged into

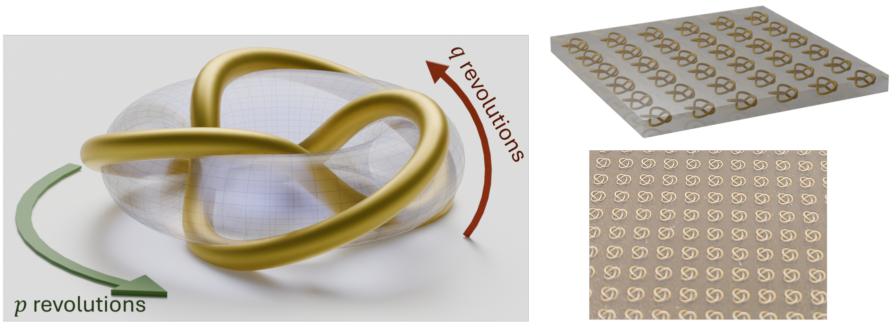

Fig. 1: Left: Knot topology on a torus surface, characterized by winding numbers (p,q) representing rotations around the torus and through its core. Top right: knot particle metasurface schematic. Bottom right: Fabricated structure.

a 2D knotted particle metasurface with a proper choice of knot features, one can achieve various electromagnetic wavefront manipulations, ranging from near-optimal polarization rotation to anomalous refraction. Here, we start by relating the knot topology to its functionality, focusing on perfectly matched polarization rotation. We show a family of knotted particles suitable for this task, related by their p, q parameters. We provide simple, analytically derived rules to adjust the knot geometry to obtain a balanced, matched operation that allows for a streamlined design process that does not require numerical optimization. Our model, relying on simplifying assumptions regarding the current distribution in each knotted wire, is then validated using full-wave simulations, which allow us to extract the scattering parameters and the actual current distribution. The results are used to extract the knot polarizability, and the surface susceptibilities, exhibiting the chiral properties.

We show two possibilities for implementation: one that utilizes advanced 3D printing, combining conducting materials and dielectrics, and the other that leverages a simplified, flat design for suitable for PCB fabrication.