Universal active metasurface modulation with ultimate performance in reflection

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Optical metasurfaces are becoming ubiquitous optical components to mold the amplitude, phase, and polarization of light. So far, most of these devices are passive in essence, that is, they cannot be arbitrarily reconfigured or optimized according to the user's interest and/or change in the surrounding environment. Here we propose an innovative design strategy relying on the position of topological singularities, namely zeros and poles of the reflection coefficient, to address full phase modulation of light reflected off an active metasurface with almost unity efficiency. The active metasurface unit cells, consisting of asymmetric Gires-Tournois resonators filled with either silicon or hetero-structured materials to leverage on the thermo-optical or electro-optical effects, respectively. In both cases, a full phase modulation associated with 100% reflection amplitude is observed even when dealing with extremely low refractive index change, on the order of 0.01. Improving the deflection efficiencies for each deflection angle and accounting for the near-field coupling between strongly resonant pixels is performed by calculating the refractive index modulation profile in the extended unit cell using an advanced optimization methodology relying on statistical learning. Consequently, active beam steering designs for active thermo-optical effect with ultimate performance exceeding 90% have been optimized. Furthermore, active wavefront splitting using electro-optics materials was optimized to reach ultimate modulation performances with nearly 92% efficiency. The realization of highly efficient active beam-forming operating at high frequencies would open important applications in imaging microscopy, high-resolution image projection, optical communication, and 3D light detection and ranging (LiDAR).