Enhancing the optical activity of chiral metasurface by a transmitted Electron Beam Lithography

Bing-Rui Lu, Zongyao Yang, Jianan Deng, Sichao Zhang, Yifang Chen

Nanolithography and Application Research Group, State key lab of Asic and System, School of Information Science and Engineering, Fudan University, Shanghai 200433, China

lubingrui@fudan.edu.cn, yifangchen@fudan.edu.cn

Conceived from the concept of natural chiral molecules with no mirror symmetry in any planes, 3-dimensional (3D) chiral metamaterials have attracted great attention for their capability to manipulate light in a peculiar manner such as negative refraction/reflection, superlensing, giant optical activity, asymmetrical transmission and circular dichroism. In order to push the functioning frequency towards the visible spectrum, the feature size of chiral metamaterial continues to shrink. The fabrication difficulties compel researchers to resort to planar chiral structures, or chiral metasurfaces, which is adaptable to the modern nano-processing techniques. Unfortunately, the chirality is usually much smaller in these structures. The implementation of multi-layer configuration of the chiral elements would dramatically improve their optical performance. However, the nano-scale metasurface is generally built on a bulky substrate, of which the effect on the chirality remains unknown. Moreover, the multi-layer fabrication normally involves an overlay process. This can lead to a mismatch between the layers, which is a disadvantage against the effort for the optical activity improvement. As a result, it is of great importance to build a free-standing multi-layered chiral metasurface in order to achieve strong chiral optical behavior without the interference from the substrate.

In our work, we propose a free-standing double-layered chiral metasurface sandwiched by a 100 nm-thick SiNx suspended membrane fabricated by a one-step self-aligned transmitted electron beam lithography (T-EBL) by a JEOL-6300FS system. A C4 symmetrical fishnet chiral sandwich system is designed to rotate the polarization angle of the input linearly polarized light. The dichroism property can also transform the linear polarization into a near-circular polarization. The T-EBL process is developed as illustrated in Fig. 1(a)-(f). The e-beam transmitting through the resist on both sides of the membrane during a single exposure ensures the precise structural overlay between the layers. The identical chiral elements on both sides of the SiNx membrane are fabricated as shown in Fig. 2. Systematic Finite Difference Time Domain (FDTD) simulations are carried out to study the cross-sectional E field distributions. Comparing to the single-layered chiral metasurface on only one side of the membrane, strong near-field coupling appears when the SiNx membrane is 100 nm or less in thickness for the double-layered counterparts. This strong coupling will lead to a dramatic improvement of the average rotation capability by 123% and a better circular dichroism property of the diffracted light as shown in Figs. 4 and 5. The ability to fabricate free-standing layered chiral metasurfaces is an essential step for it to find practical applications with improved optical activities such as negative refraction/reflection, superlensing, optical dichroism components as well as nonreciprocal transmission devices.

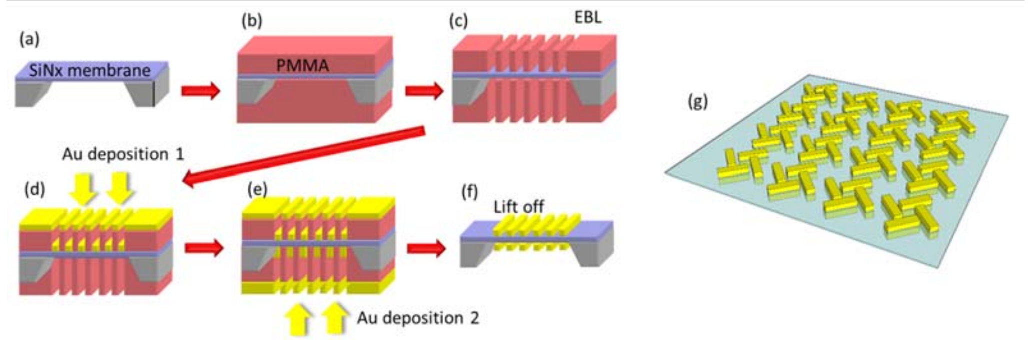

Figure 1: The fabrication process for a free-standing double-layered chiral metasurface and the illustration of the structural design.

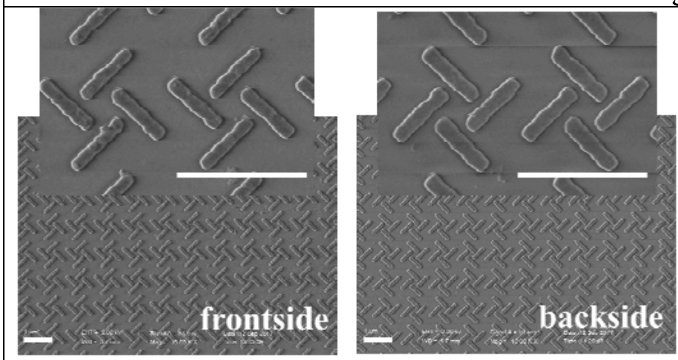

Figure 2: The SEM images of the fabricated chiral elements on the front and back sides of the suspended SiNx membrane.

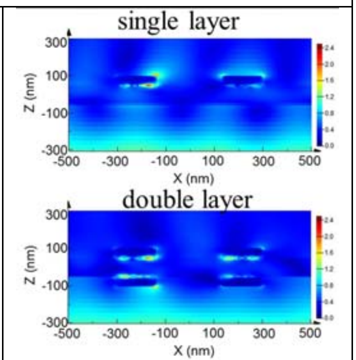

Figure 3: The FDTD simulations for the cross-sectional E-field.

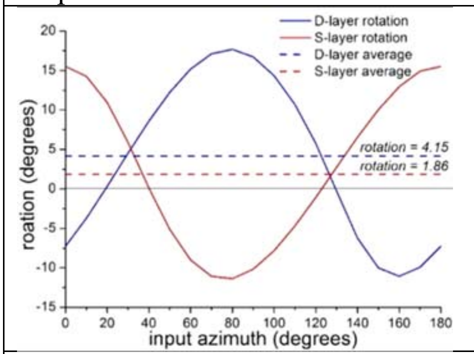

Figure 4: The rotation of the major polarization angle changes with the input azimuth. The average rotation is increased by 123% with a double-layered structure.

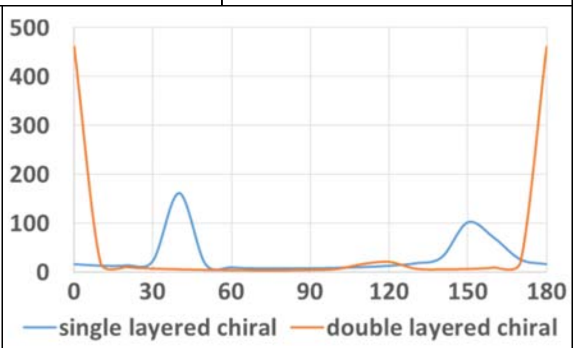

Figure 5: The double layered chiral structures demonstrate stronger dichroism properties in the diffracted light, which is more likely to turn the linearly polarized input light into a circularly polarized light.