3D bidirectional deformation nanostructures by focused ion beam bidirectional origami method for multichannel chiral metasurface

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Origami as an ancient art of paper folding, provides a means that transform the 2D sheet into 3D regime, fascinating structures can be taken shape by this art [1,2]. Origami structures in micro/nanoscale give numbers of opportunities to the new photonics devices and electronic devices for its high spatial controllability. Thus, choosing a driven force and bringing the origami into mesoscale have attracted considerable concerns, driven force including residual stress [3], buckling force [4], capillary force [5] has been efficiently used in the origami fabrication. However, the origami structures are hard to be fabricated in nanoscale for most of the driven forces do not work in such a small space. Consequently, the applications of the origami, especially the photonics device that rely on the wavelength or subwavelength scale configuration are seriously hindered. It is urgently needed to find a powerful driven force and achieve the nanoorigami.

In this work, we choose the stress that introduced from FIB-mater interaction to drive the flat cantilevers into nanoscale bidirectional origami structures, and a dual functional chiral metasurface was demonstrated with giant CD. The FIB irradiation leads to local vacancy defects and implanted ions, resulting in a nanoscale tensile or compress stress, which can bending/folding the cantilever into a nanoorigami structure. Notably, the type of the generated stress is varied by materials. When it comes to the Al film, the stress can be changed from a compress stress to a tensile one due to the sputtering rate and the grain size change, which means that the deformation direction of Al film can be regulated by the FIB irradiation dose (Figure 1a). The bidirectional origami does not relate on the shape and the arrangement of the cantilevers, thus Figure 1b further shows a series of bidirectional origami nanostructure, indicating that the structures obtained by FIB defined origami have great diversity. The multidimensional spatial controllability gives a new chance for the light regulation devices, and a metasurface consists of a subwavelength bidirectional split ring resonator (SRR) array is designed and fabricated as shown in Figure 2a. A superior consistency can be found between the design and experiment. Due to the dipoles interaction, the simulation of the metasurface shows a two-band spin selective transmission of chiral light, giant CDs of 0.85 and -0.86 can be observed at 5.12 μm and 11.33μm, respectively (Figure 2b). Moreover, the experimental results show a CD of 0.78, confirms the correctness of simulation.

FIB defined bidirectional origami provides a new routine to the fabrication of nanoscale, multidimensional controllable 3D nanostrucutres, which is very conducive to the assembly of chiral metasurfaces with giant CDs. Most importantly, it is expected to establish a robust fabrication platform in the broader fields including micro/nano-photonics, optoelectronic, and mechanical devices, etc.

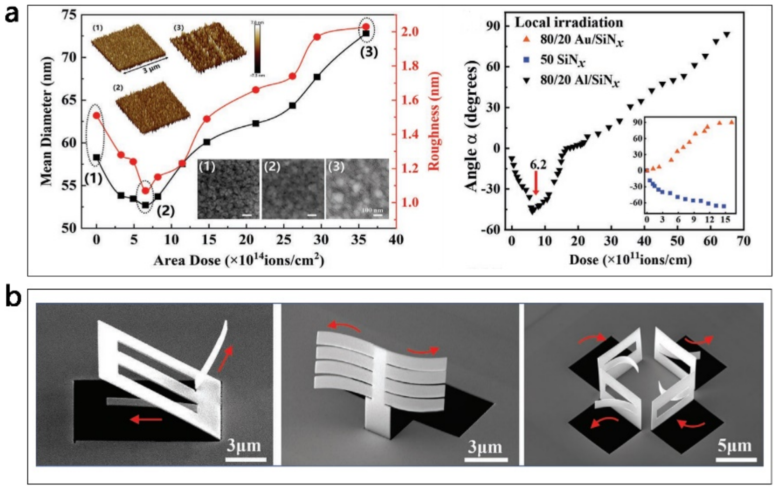

Figure 1 (a) The grain size, surface roughness and the deformation angle of Al film with different FIB irradiation dose; (b) Diversified nanostructures with bidirectional origami configurations.

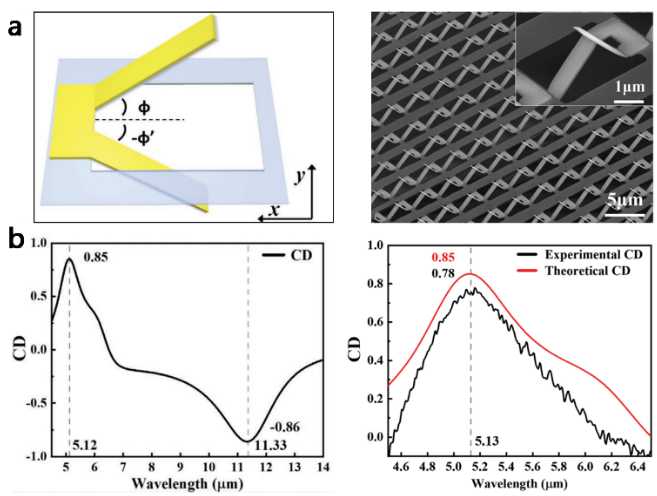

Figure 2 (a) Schematic and SEM image of chiral consists of bidirectional origami SRRs; (c) Simulated and experimental CD spectra of the origami metasurface

References

[1] J. H. Na, A. A. Evans, J. Bae, M. C. Chiappelli, C. D. Santangelo, R. J. Lang, T. C. Hull, and R. C. Hayward, Adv. Mater. **27**, 79 (2015).

[2] J. L. Silverberg, A. A. Evans, L. McLeod, R. C. Hayward, T. Hull, C. D. Santangelo, and I. Cohen, Science **345**, 647 (2014).

[3] K. Chalapat, N. Chekurov, H. Jiang, J. Li, B. Parviz, and G. S. Paraoanu, Adv. Mater. **25**, 91 (2013).

[4] H. Fu *et al.*, Nat Mater **17**, 268 (2018).

[5] C. Py, P. Reverdy, L. Doppler, J. Bico, B. Roman, and C. N. Baroud, Phys. Rev. Lett. **98**, 156103 (2007).