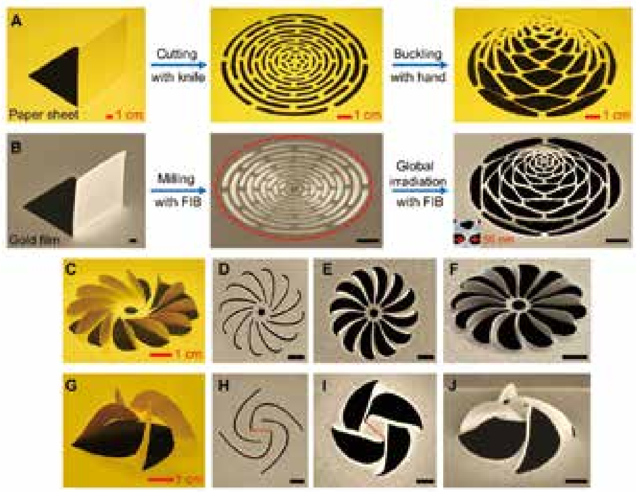
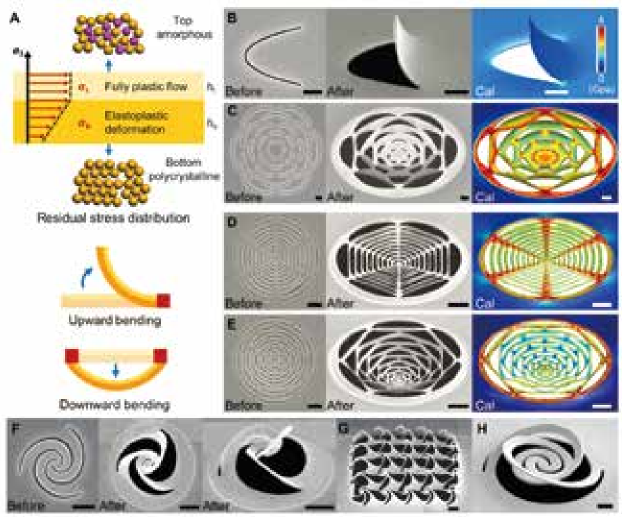
Nano-Kirigami: A Nanoscale "Paper-cut" Developed For 3D Intelligent Nanofabrication

Kirigami is one of the most traditional Chinese arts (named "paper-cuts" or "*jianzhi*") that has been widely used in window decorations, gift cards, festivals, ceremonies, etc. Through cutting and folding flat objects into 3D shapes, the knowledge of kirigami has recently aroused tremendous interests in both sciences and technologies, including deployable designs of solar arrays, biomedical devices and micro-/ nano- electromechanical systems (MEMS/NEMS). Now, Dr. LI Jiafang from the Institute of Physics (IOP), Chinese Academy of Sciences (CAS) has initiated an international effort to apply this ancient art to advanced 3D nanofabrication. The collaborative team includes PhD student LIU Zhiguang at IOP, graduate student DU Huifeng and Prof. Nicholas X. Fang at Massachusetts Institute of Technology, Prof. LI Zhiyuan at the South China University of Technology and Prof. LU Ling at IOP.



Macroscopic paper-cuts in a paper sheet and nano-kirigami in an 80-nm thick gold film. (Image by IOP)

Inspired by a traditional Chinese paper-cut named "pulling flower", the team developed a direct nano-kirigami method in flat films at the nanoscale. They utilized focused ion beam (FIB) instead of knives/ scissors to cut a precise pattern in a free-standing gold nanofilm, and used the same FIB instead of hands to gradually "pull" the nanopattern into a complex 3D shape. The "pulling" forces were induced by heterogeneous vacancies (introducing tensile stress) and the implanted ions (introducing compressive stress) within the gold nanofilm during FIB irradiation. By utilizing the topography-guided stress equilibrium within the nanofilm, versatile 3D shape transformations such as upward buckling, downward bending, complex rotation and twisting of nanostructures were precisely achieved.



Topography-guided nano-kirigami and mechanical modelling. (Image by IOP)

While previous attempts to create functional kirigami devices have used complicated sequential procedures and have been primarily aimed at realizing mechanical rather than optical functions, this new nano-kirigami method, by contrast, can be implemented in a single fabrication step and could be used to perform a number of optical functions. For a proof-of-concept demonstration, the team produced a 3D pinwheel-like structure with giant optical chirality. The nanodevice achieved efficient manipulation of "left-handed" and "right-handed" circularly polarized light and exhibited strong uniaxial optical rotation effects in telecommunication wavelengths. In such a way, the team demonstrated a multidisciplinary connection of two fields, nanomechanics and nanophotonics, which may represent a brand-new direction for the emerging kirigami research.

The team also developed a theoretical model to elucidate the dynamics during the nano-kirigami. This is of great significance since it allows researchers to inversely design 3D nanogeometries based on desired optical functionalities, while previous studies relied heavily on intuitive designs. Therefore, in the aspect of geometric designs, the nano-kirigami offers an intelligent 3D nanofabrication method beyond the traditional bottom-up, top-down and self-assembly nanofabrication techniques. Its concept can be extended to broad nanofabrication platforms and could lead to the realization of complex optical nanostructures for sensing, computation, micro-/nano- electromechanical systems or biomedical devices.

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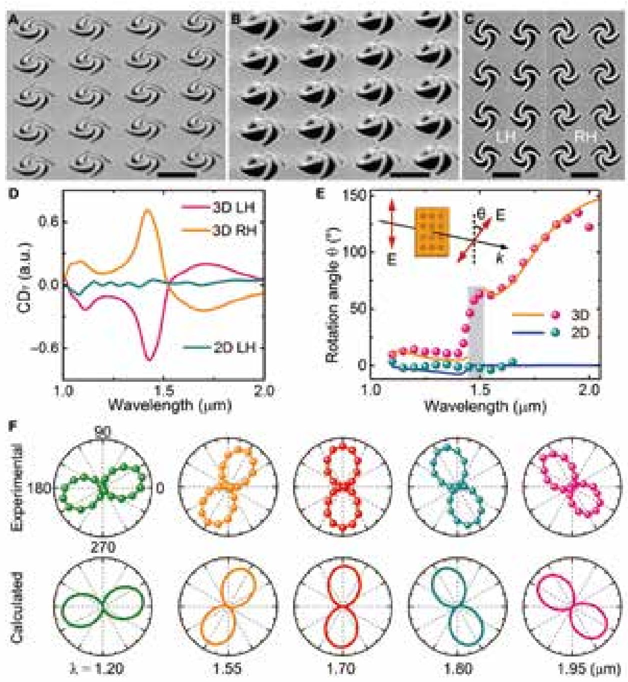

Functional designs of nano-kirigami structures with giant optical chirality. (Image by IOP)

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