A clever twist

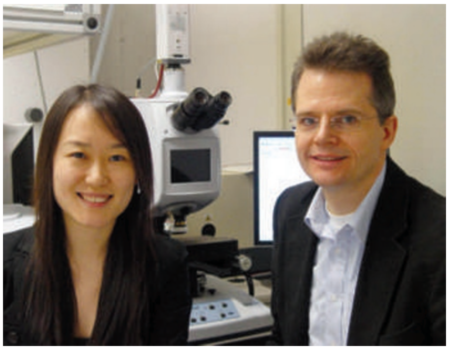
It has now been shown that twisting the orientation of layers in a metamaterial provides a new way of tailoring their electromagnetic properties. *Nature Photonics* spoke to Harald Giessen and Na Liu from the University of Stuttgart about the idea.

What is a metamaterial and why are they interesting?

A metamaterial is an artificially engineered material made from an array of unit cells that are carefully designed to produce a desirable electromagnetic response. A common design of unit cell is the so-called split ring resonator (SRR), a tiny metal ring-shaped structure featuring a miniature gap. Changing the size, geometry and composition of the resonator determines the electromagnetic properties of the metamaterial and its wavelength of operation. Such metamaterials are being investigated for a wide variety of applications ranging from the development of materials with a negative refractive index to those that can perform cloaking or act as a perfect lens.

How did you get the idea of making twisted metamaterials?

Initially, we were studying a four-layer stacked SRR structure. We found that at normal incidence, the electric coupling between neighbouring layers dominates and determines the optical properties of the structure. Later, we came up with a design called "metaDNA", which consists of multiple layers of 90° twisted SRRs. In this case, the magnetic coupling has a key role. This made us wonder about the roles of electric and magnetic interactions in stacked SRRs with different geometries. In order to solve this riddle, we simplified the problem to stacked SRR dimers with twist angles of 0°, 90° and 180°. Subsequently, we were able to understand the electric and magnetic coupling in these three structures by utilizing the method of plasmon hybridization from Peter Nordlander, a well-known chemist at Rice University, USA. One day, Stefan Linden, an expert in metamaterials from Karlsruhe, visited our lab, looked at our structures and suggested, "Why not take a further step and twist the structures from 0° to 180°?". We followed his suggestion and began new studies. In the end, we could not only logically understand but also analytically describe the evolution of electric and magnetic interactions with



HARALD GIESSEN

Na Liu and Harald Giessen from the University of Stuttgart in their laboratory.

twist angle, using the Lagrangian model of our collaborator Hui Liu [one of the co-authors of the paper on page 157 of this issue] from Nanjing University.

Why did you decide to call your structures "stereometamaterials"?

The exact word "stereometamaterials" was generated during a discussion over the phone between Na Liu and Hui Liu. In fact, we are both admirers of Peter Nordlander and his insight into plasmonics using the hybridization method from chemistry. We suspected that as the resonant behaviour of stacked SRRs with specific angles of orientation can be understood by plasmon hybridization, there might already be some established system or model in chemistry that was analogous to our twisted metamaterial system. Finally, we found the term stereochemistry, which is a subfield of chemistry, which studies how the spatial arrangement of atoms within molecules determines the properties of chemical substances. As a result, we decided to call our structures "stereometamaterials".

What kind of applications could such stereometamaterials have?

One of the most obvious applications of stereometamaterials is optical polarization control. Because the polarization properties of adjacent metamaterial layers can be different, by introducing appropriate phase shifts between these layers, the polarization of the transmitted wave is highly tunable. It would also be very interesting to study the chiral effects of twisted structures, especially left- and right-twisted ones, namely enantiomers. As predicted by Sir John Pendry, the strong chirality can allow the realization of a negative refractive index without requiring simultaneous negative permittivity and negative permeability. Negative refraction may result from the cross-coupling of the electric and magnetic response. With proper design of stereometamaterials, the electric and magnetic dipoles can have parallel components, giving rise to negative refraction for circularly polarized light. You could also imagine having polarization rotation devices made from a material that is a few hundred nanometres thick — two or three layers that are custom-designed to have great efficiency. Sensing is also a possibility as these structures can show electromagnetically induced transparency and thus very narrow resonances which can be used for sensing or generating slow light.

What are your plans for future work in this area?

Future research will include studies on how to make use of higher-order electric multipolar and magnetic interactions, which can be nearly as large in these systems as the electric dipolar interaction. Also, the influence of the structural geometry on the material's optical properties, and the distance dependence of stereometamaterial coupling, are intriguing. More analogies between artificial metamaterial molecules and real molecules in chemistry might be discovered in the future. Additionally, these metamaterial molecules, which can be realized according to a designer's plan, may be able to emulate liquid crystals, chiral proteins and drug enzymes, leading to useful applications in biophotonics.

INTERVIEW BY OLIVER GRAYDON

Giessen and co-workers have a paper on the topic of stereometamaterials on page 157 of this issue.