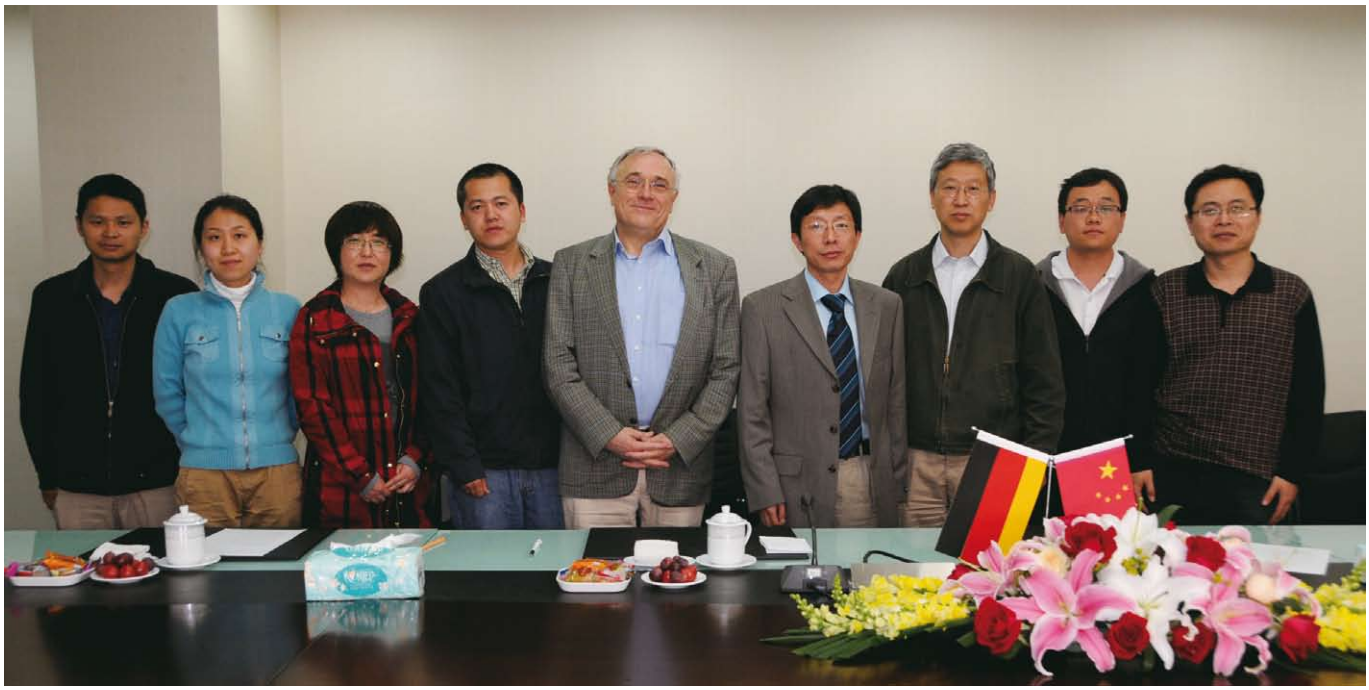
Carbon of Magical Structures

CAS/MPG Partner Group on Carbon-Rich Nanomaterials
Beijing-Mainz, 2010.5.1–2015.4.30



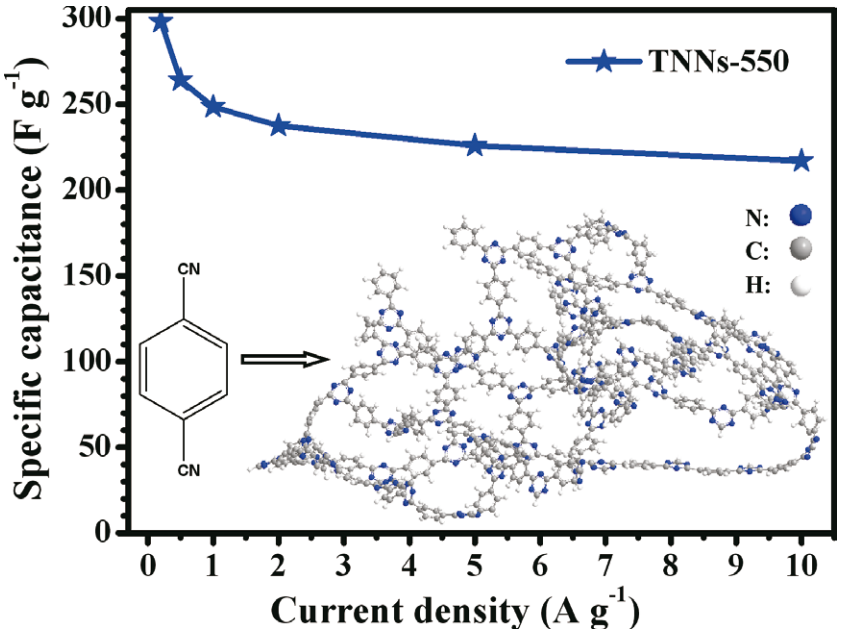
Prof. Dr. Klaus Müllen (middle), Prof. WANG Chen (Director of NCNST and Board Member of the Partner Group), and Prof. Dr. ZHI Linjie with the Partner Group members at the signing ceremony for a collaboration agreement between the Max-Planck-institute for Polymer Research (MPIP) and the National Center for Nanoscience and Technology (NCNST).

As one of the Partner Groups which were initiated to promote scientific exchanges and collaborations between the Max Planck Society (MPS) and the Chinese Academy of Sciences (CAS), the Partner Group led by Prof. Dr. ZHI Linjie was established on May, 2010. During the past three years, the group received substantial support from the CAS and the Max-Planck-Institute for Polymer Research (MPIP) for extensive exchanges and collaborations on carbon-rich nanomaterials. Productive collaborations between the researchers and the students from the National Center for Nanoscience and Technology (NCNST) and the MPIP as well as the collaborations between the Partner group and other research groups in Germany have produced significant advances in synthesis, assembly and applications of functional carbon-rich nanomaterials as well as their molecule precursors. The research is well recognized internationally and a considerable number of papers have been published in high quality, peer-reviewed journals such as *J. Am. Chem. Soc.* and *Adv. Mater.*

With the support of the Partner Group, Prof. Dr. ZHI Linjie has collaborated with Prof. Arne Thomas on carbon-rich molecules and their corresponding functional carbon-rich nanomaterials, with Prof. Dr. Klaus Müllen on assembly and construction of functional nanostructures, and with Dr. Michael Giersig on functional devices.

Reported by Group Leader ZHI Linjie

Photos/Images: By courtesy of Prof. ZHI Linjie.



Specific capacitances at various current densities for terephthalonitrile-derived nitrogen-rich carbonaceous networks (TNNs) with illustration of its synthesis procedure in the inset.

MAJOR RESEARCH THEMES OF THE COLLABORATION

1. Carbon-rich molecules and their thermal reactions towards novel nanomaterials

The bottom-up approaches represent an ideal strategy to develop functional nanomaterials in a controlled and tunable manner. The partner group has developed a variety of functional carbon-rich nanomaterials with and/or without incorporating heteroatoms such as nitrogen and sulfur, by diverse bottom-up synthetic formulae based on different chemical reactions. These new and originally-explored carbonaceous nanomaterials show great potential in applications such as energy conversion, energy storage, catalysis, among others. The impacts of the research activities of Prof. Dr. ZHI Linjie through the Partner Group is enormous, especially in light of the structure-property relationships of this kind of nanomaterials originally unraveled with the support from the Partner Group funding.

SELECTED PUBLICATIONS

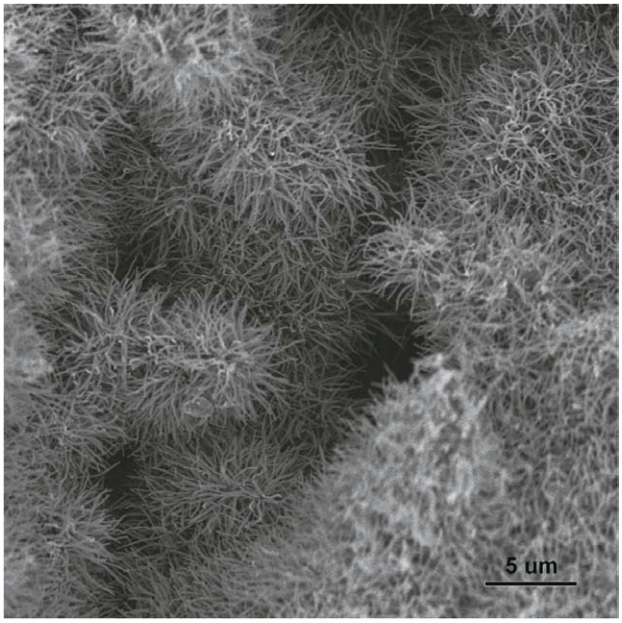
1. Hao, L.; Luo, B.; Li, X.; Jin, M.; Fang, Y.; Tang, Z.; Jia, Y.; Liang, M.; Thomas, A.; Yang, J.; & Zhi, L. (2012) Terephthalonitrile-derived nitrogen-rich networks for high performance supercapacitors, *Energy Environ. Sci.*, 5, 9747.
2. Yang, S.; Feng, X.; Zhi, L;, Cao, Q.; Maier, J.; & Müllen, K. (2010) Nanographene-constructed hollow carbon spheres and their favorable electroactivity with respect to lithium storage, *Adv. Mater.*, 22, 838.

2. Self-assembly behavior of carbon-rich molecules and the formation of functional nanostructures

Organization and order of discotic nanographene units as organic semiconductors are important for their performances. Prof. Dr. ZHI Linjie and his collaborators systematically investigated the assembly behaviors of various hexa-peri-hexabenzocoronenes (HBCs), the building blocks of two-dimensional (2D) graphene sheets, in terms of structural parameters and experimental conditions such as the type of solvents and the nature of the substrate surfaces. The relationships elucidated provide a quite deep insight into the molecular design and self-assembly of new discotic nanographene materials towards advanced sensing and electronic devices.

SELECTED PUBLICATIONS

1. Yin, M.; Shen, J.; Wojciech, P.; Liang, M.; Zhi, L.; & Müllen, K. (2009) Functionalization of self-assembled hexa-peri-hexabenzocoronene fibers with peptides for bioprobing, *J. Am. Chem. Soc.*, 131, 14618.
2. Feng, X.; Pisula, W.; Kudernac, T.; Wu, D.; Zhi, L.; Feyter, S. D.; & Müllen, K. (2009) Controlled self-assembly of C-3-symmetric hexa-peri-hexabenzocoronenes with alternating hydrophilic and hydrophobic substituents in solution, in the bulk, and on a surface, *J. Am. Chem. Soc.*, 131, 4439.



The team successfully fabricated Carbon-shell/Sn-core nanocables from graphene/SnO_2 nanocomposite for the purpose of improving the contact efficiency between Sn and carbon; this makes it possible to achieve significantly enhanced electrochemical properties when the nanocables are used as electrodes in litnium ion batteries.

3. Nanolithography and the fabrication of various functional nanodevices

The Partner Group fabricated the devices of individual stacked-graphene carbon nanotube (SG-CNT) based on electron-beam (e-beam) lithography, as well as unraveled their temperature-dependent electrical transport properties in the dark, and their electrical responses to photo-illumination. It is important to note that the electrical resistivity of individual SG-CNT can be nearly five times larger than for graphite crystals perpendicular to their basal planes. Besides, the partner group developed novel magnetic nanocavity device structures based on self-assembled nanosphere lithography. The optical transmission measurements show that such device structures are highly sensitive to the presence of magnetic nanoparticles inside the nanocavities, representing an efficient strategy useful for a wide range of applications, such as surface sensing.

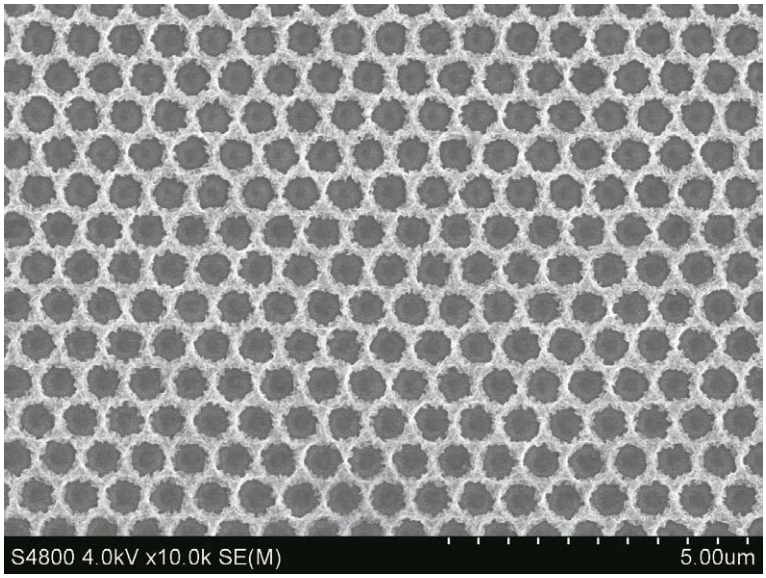
SELECTED PUBLICATIONS

1. Lee, E. J. H.; Zhi, L.; Burghard, M.; Müllen, K.; & Kern, K. (2010) Electrical properties and photoconductivity of stacked-graphene carbon nanotubes, *Adv. Mater.*, 22, 1854.
2. Patoka, P.; Skeren, T.; Hilgendorff, M.; Zhi, L.; Paudel, T.; Kempa, & K.; Giersig, M. (2011) Transmission of light through magnetic nanocavities, *Small*, 7, 3096.

POTENTIAL RESEARCH THEMES FOR FUTURE COOPERATION

1. Functional carbon-rich nanomaterials doped with heteroatoms

Investigation of functional nanomaterials is currently one of the central topics in the field of materials science and has also been a core focus of the Partner Group in the past three years. The Partner Group will exploit several novel kinds of carbon-rich materials and graphene-based nanomaterials, for example, by employing polycyclic aromatic hydrocarbons containing at least two kinds of heteroatoms such as sulfur, nitrogen, and phosphorus to develop multifunctional heteroatom-doped carbon-rich materials and graphene-based nanomaterials. The objective is to identify the intrinsic role of heteroatoms in determining the properties of carbon-rich nanomaterials and to discover functional carbon-rich nanomaterials with



Well-defined MnO_2 nanostructures uniformly deposited on the surface of Au nanomesh prepared by the team via nanolithography techniques. This successful manipulation might herald a new type of high-performance transparent supercapacitors.

new and unknown properties, which would provide insight into the design and tuning of carbon-rich materials with desirable functionalities. It can be expected that this continuous design and production of novel carbon-rich materials and graphene-based nanomaterials, combined with the related precursor-product-property relations revealed during this close incorporation secured by the Partner Group, will form a versatile modular toolbox for energy and environmental applications.

2. Miniaturized devices of individual functional carbon-rich nano-objects

Novel miniaturized device prototypes consisting of individual carbon-rich nano-objects (self-assembled molecules and carbonaceous nanomaterials) will be fabricated via E-beam and/or ion beam lithography, aiming to not only construct really implantable miniaturized functional devices for diverse applications, but also disclose the functioning mechanism of this kind of materials units in various applications such as energy-related systems including lithium ion batteries, supercapacitors, and fuel cells. Electrochemical properties of the carbon-rich heteroatom-doped nano-objects will be investigated at the materials unit scale. It would be expected that the study of these novel materials or materials superstructures integrated within a miniaturized device can lead to a more direct and explicit correlation of the materials' chemical structure, components and properties. ◀

INFO

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