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Please take a look at the issue 12 2011 table of contents to access other reviews in this themed issue
In the current research age, DNA has emerged out of its biological role and is being used more and more as an intelligent construction material, where the DNA acts both as stick and glue. The chemical synthesis of natural and modified DNA nowadays has become routine, and DNA-based new functional materials are being designed by a large number of research groups around the globe. The evolution of DNA nanotechnology would not have been possible without the efforts put into DNA synthesis, analysis and sequence design. Since the theoretical paper of Nadrian Seeman hypothesising the use of DNA in biotechnology,\(^1\) a large diversity of 2D and 3D constructs have been realised through clever design of DNA sequences, and using appropriate sticky end approaches. The DNA can be used to form 2D and 3D crystals, origami shapes and 3D objects. DNA is also being used to create molecular motors and robots, which are capable of autonomous walking along specific DNA tracks, or as templates for directed synthesis of organic molecules. The DNA robots are capable of performing tasks such as picking up and delivering cargoes. Both natural and chemically modified DNAs are being used widely. In addition, modified nucleotides are very important in the study of biological systems which involve DNA synthesis or replication. The development in the field of DNA architectonics reaches into many areas of research, including electronics, diagnostics, medicinal applications, materials science and synthetic biology. It is therefore timely to compile a themed issue of *Chem Soc Rev* on DNA-based nanotechnology to highlight the recent advances. This issue comprises an excellent collection of both tutorial and critical reviews from across the field and the globe. The breadth of the research themes clearly demonstrates that DNA will play an important role in the future of nano-biotechnology.

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**DNA in a modern world**

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\(^{1}\)Part of a themed issue on the advances in DNA-based nanotechnology.

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Eugen Stulz graduated from the University of Bern (Switzerland) in 1994, where he subsequently studied for a PhD under the supervision of Prof. Christian J. Leumann. In 1999, he moved to Cambridge (UK) as a Swiss National Science Foundation Postdoctoral fellow to the group of Prof. Jeremy K. M. Sanders. In 2003, he moved to the University of Basel (Switzerland) as a Lecturer (Habilitand) and started his independent research in the field of supramolecular chemistry using DNA as scaffold. In 2006, he was appointed Lecturer at the School of Chemistry, Southampton, and promoted Senior Lecturer in 2010. His research interests include supramolecular systems for applications in artificial photosynthesis, molecular electronics, DNA nano-biotechnology, chemical biology, diagnostics and cancer therapy. Eugen Stulz was awarded a Swiss National Science Advanced Research fellowship (2000–2002), and a Fellowship by the TREUBEL Foundation Basel (2005–2006).

Guido Clever studied Chemistry and Molecular Biology at the University of Heidelberg. After graduation in 2003, he moved to the University of Marburg to join the group of Thomas Carell. Supported by an FCI Kekulé fellowship, he received his Doctorate in Bio-Organic Chemistry from LMU Munich in 2006 for his work on the development of an artificial metal-salen base pair yielding stacked metal arrays inside DNA double helices. From 2007–2009, he was a Postdoctoral Researcher in the group of Mitsuhi Shionoya at the University of Tokyo. In 2009, he was appointed as a Project Assistant Professor at the University of Tokyo and in 2010 he accepted a call to the University of Göttingen (Germany) as a Junior-Professor (W1) for Inorganic Chemistry. His research interests are in the field of Supramolecular Coordination Chemistry with a focus on dynamic DNA nanoarchitectures and the interaction of functional guest compounds with metal-mediated coordination cages.
materials science, supramolecular chemistry and synthetic biology.

The reviews also demonstrate the overlap of the fields in terms of applications. Both basic studies, including synthesis and analysis, as well as applications in materials science, biology and medicine are covered in many of the reviews, thus a classification according to content is difficult to make. However, some common themes seem to emerge from the various applications described, which are broadly divided into synthesis of DNA and hybrid materials, bio-synthesis of DNA, use of DNA as a platform for nano-structures, and use of synthetic DNA to analyse biological and medicinal effects.

The synthesis of alternative base pairs is reviewed by Wojciechowski and Leumann (DOI: 10.1039/c1cs15027h); these are used to expand the genetic code but also find potential applications in materials science. Antisense oligonucleotides and siRNA research is very important in view of therapeutic purposes; the approach of using enzymatically stable LNA and UNA in this respect is reviewed by Campbell and Wengel (DOI: 10.1039/c1cs15048k). Sasaki and colleagues (DOI: 10.1039/c1cs15066a) review the development of new oligodeoxynucleotide probes for the site-specific modification of RNA. These tools allow the introduction of modifications such as fluorescent labels into RNA strands which is of utmost importance for the study of the complex biological functions of RNA. The stereocoupled synthesis of modified oligonucleotides containing chiral internucleotidic phosphorus atoms is reviewed by Oka and Wada (DOI: 10.1039/c1cs15102a). These compounds are of importance for the development of therapeutic agents and the elucidation of enzymatic mechanisms.

Hybrid lipid oligonucleotide conjugates are described by Barthélémy and colleagues (DOI: 10.1039/c1cs15038c). Such hybrid DNA materials can self-assemble and the biomedical applications are reviewed. Kwak and Herrmann (DOI: 10.1039/c1cs15138j) review the field of nucleic acid amphiphiles, which are also capable of forming self-assembled nanostructures. Dohno and Nakatani (DOI: 10.1039/c1cs15062f) describe in their review the reversible control of DNA hybridisation by photo-switchable compounds acting as molecular glue which opens the possibility for interesting new applications in DNA-based nanoscience. Østergaard and Hrdlicka (DOI: 10.1039/c1cs15014f) review the synthesis and applications of pyrene-functionalised oligonucleotides (PFOs), particularly pyrene-functionalised locked nucleic acids (LNAs). The uniqueness of the PFOs comes from the environment-sensitive chromophore, pyrene. Ono and colleagues (DOI: 10.1039/c1cs15149e) discuss in their contribution the binding of the metal ions mercury(ii) and silver(i) between the pyrimidine base pairs TT and CC, respectively. Since subtle chemical modification of the pyrimidines has been shown to fine-tune the metal binding abilities, this approach has gained relevance in a large number of bio-nanotechnological systems.

DNA can be synthesised using enzymatic methods, i.e. PCR. Keller and Marx (DOI: 10.1039/c1cs15040e) present an overview of the enzyme-catalysed construction of DNA-based objects and assemblies and illustrate how a diversity of enzyme-based biochemical reactions can be transferred in nanotechnological applications. Analytical applications including DNA hybridisation, primer extension, PCR, SNP typing, DNA damage and DNA-protein interaction analysis are discussed by Hocek and Fojta (DOI: 10.1039/c1cs15049a); the redox DNA labelling for electrochemical detection of DNA relies on both synthetic and enzymatic synthesis of the modified DNA. Fluorescence-based nucleic acid sensors are used widely in bioanalytics, such as probing enzyme activities and detecting small molecules. Dai and Kool

Mitsuhiko Shionoya received his BS (1982) and MS (1984) degrees from the University of Tokyo. In 1986 he accepted a position as Assistant Professor at Hiroshima University. In 1988 he moved to the Institute for Molecular Science in Okazaki with Prof. Eiichi Kimura. He received his PhD from Hiroshima University in 1990 and moved back to Hiroshima University. He was promoted to Associate Professor (1994). In 1995, he was appointed as a Professor at the Institute for Molecular Science in Okazaki. In 1999, he was appointed as a Professor at the Graduate School of Science, the University of Tokyo. His research interests involve bio-inspired molecular architectures using metal complexes and biomolecules such as (artificial) DNA and peptides, molecular machines, supramolecular porous crystals, and nano- to submicron-sized molecular aggregates. He was awarded the Chemical Society of Japan Award for Creation Work (2007), Inoue Prize for Science (2007), and University of Louis Pasteur Medal (2008).

Chengde Mao is an associate professor in the department of Chemistry at Purdue University. He received his BS in chemistry from Beijing University (1986) and PhD in chemistry from New York University (1999). After postdoctoral training at Harvard University, he joined the faculty of Purdue University in 2002. His current research interest includes programmed DNA self-assembly, nanopatterning, and their applications in biomedical research.

Mitsuhiko Shionoya

Chengde Mao
One of the most exciting developments in structural DNA nanotechnology is the DNA origami technology developed by Paul Rothemund. As reviewed by Yan, Gothelf and colleagues (DOI: 10.1039/c1cs15057j), DNA origami has been used to assemble complex 2D and 3D nanostructures in the past five years. As generic polymeric materials, DNA can assemble in large quantities. Luo and colleagues (DOI: 10.1039/c1cs15162b) review some real-world applications of DNA nanomaterials. In view of using DNA as construction material, Sleiman and colleagues (DOI: 10.1039/c1cs15253j) discuss supramolecular DNA assemblies. They highlight how the powerful self-assembly of DNA can be used as a unique template to finely organise and control matter on the nanometre scale.

Oligonucleotides are also a versatile platform to create assemblies of proteins, which are important for protein detection, drug discovery and structural characterisation of protein targets. Diezmann and Seitz (DOI: 10.1039/c1cs15054e) review how different scaffolds can be used to control localisation, structure and bioactivity of proteins and protein ligands. Sacca and Niemeyer (DOI: 10.1039/c1cs15212b) discuss the conjugation of proteins with synthetic oligonucleotides, which are then used in a variety of applications, ranging from biomedical diagnostics to DNA-based nanofabrication. In addition, DNA has been demonstrated to encode small molecules through covalent conjugation and promote chemical synthesis. Liu and colleagues (DOI: 10.1039/c1cs15076f) review the in vitro evolution of DNA-encoded small molecule libraries and discovery of bioactive synthetic small molecules.

The secondary structure of DNA is very important in biology; particularly G-quadruplexes are associated with regulation of gene expression and genome maintenance. Collie and Parkinson (DOI: 10.1039/c1cs15067g) review the current structural database of folding topologies, molecular interfaces and novel interaction surfaces, with a consideration to their future exploitation in drug discovery, molecular biology, supramolecular assembly and aptamer design. Komiyama and colleagues (DOI: 10.1039/c1cs15039a) review the recent developments in the field of site-selective cutters for the scission of DNA strands with broad applications in molecular biology and biotechnology. Such constructs consisting of a DNA-cutting moiety and a sequence recognising part exhibit a remarkable site-selectivity allowing the targeting of a single restriction site in an entire genome. Choi and Majima (DOI: 10.1039/c1cs15153c) discuss the conformational changes of non-B type DNA, that form under certain conditions such as hairpins, triplexes, tetraplexes, left-handed Z-form, G-quadruplexes, i-motif and A-motif. Light is shed on the role of non-B type DNA conformations in disease development and their application in DNA-based nanotechnology. Okamoto (DOI: 10.1039/c1cs15025a) reviews the recent advances in exciton-controlled hybridisation-sensitive fluorescent oligonucleotide (ECHO) probes. This new technique has led to a number of practical applications such as multicolor imaging of RNA sequences in living cells and the detection of gene polymorphisms.

We would like to extend our gratitude to all authors who have contributed to the success of this themed issue, and also to all researchers who are continuing to drive this exciting interdisciplinary field forward.

References