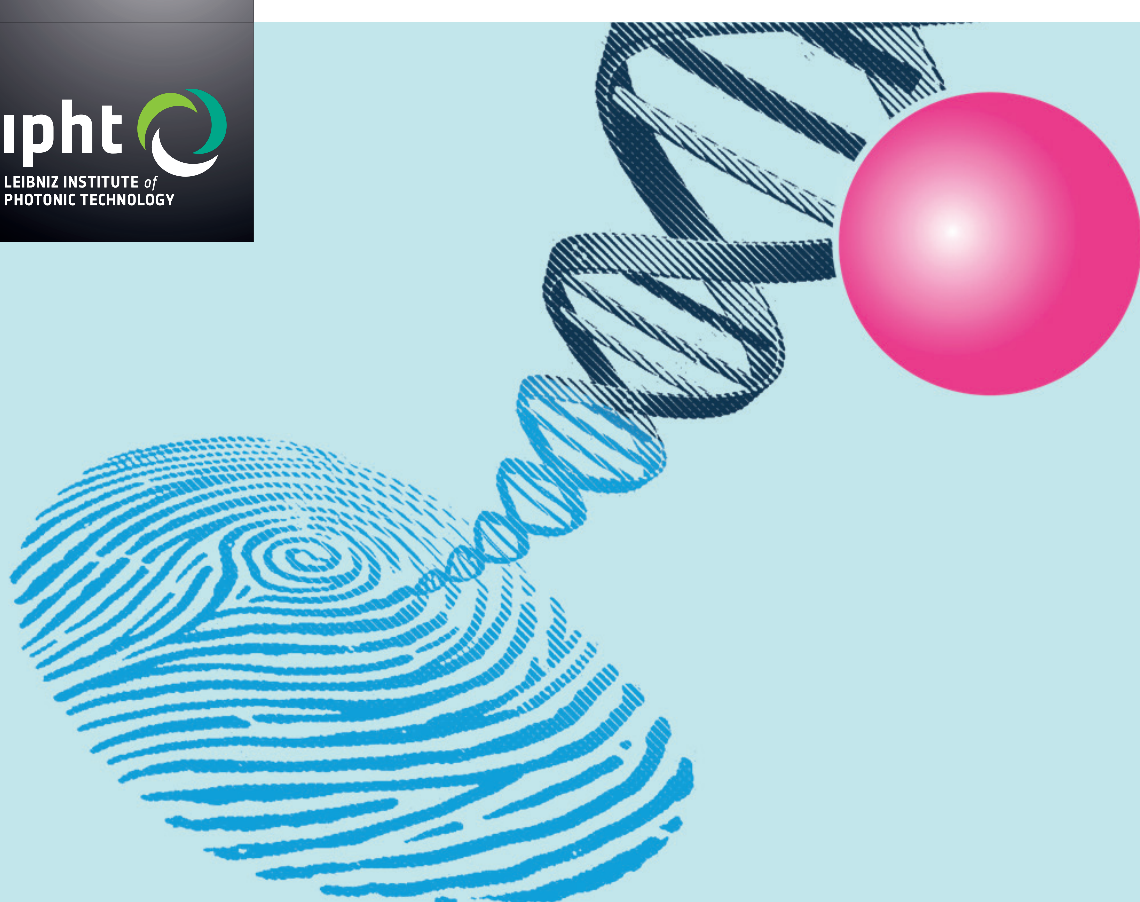
Leibniz ipht
LEIBNIZ INSTITUTE of PHOTONIC TECHNOLOGY



ABSTRACTS

DNA NANOTECHNOLOGY 2026

MAY 7 – MAY 9, 2026

Leibniz IPHT // Campus Beutenberg // Jena

www.leibniz-ipht.de

Leibniz Association

PROGRAM

THURSDAY, MAY 7, 2026

Leibniz IPHT, Campus Beutenberg (Bus no. 10, 11, 12)

12:30 **Satellite-Workshop "DNA Mitteldeutschland", free to join // Get-together**
(lunch suggestion: Foodtruck at Beutenberg Campus: https://www.foodtruck-thueringen.de/)

13:00 **Presentations**

17:00 END

Bus to downtown + 10 min walk, or appr. 40 min walk
Restaurant Del. Corazón, Downtown (at historical market place)

18:30 **Get-Together**

19:00 DINNER

FRIDAY, MAY 8, 2026

Leibniz IPHT, Campus Beutenberg (Bus no. 10, 11, 12)

8:30 **Registration**

9:00 **Opening & Introduction** // Wolfgang Fritzsche

9:05 Session 1 // Wolfgang Fritzsche

DNA-Based Constitutional Dynamic Networks and Transient Dissipative Reaction Circuits // Itamar Willner (Jerusalem)

Fundamental studies of SELEX: from thermodynamics to kinetics // Juewen Liu (Waterloo)

DNA-programmed assembly of bispecific agents targeting receptor pairs on cancer cells // Oliver Seitz (Berlin)

10:20 COFFEE BREAK

11:00 Session 2 // Itamar Willner

Electroactuated DNA Origami Nanolevers Enable Molecule Friction Sensing of Protein Conformational Changes // Ulrich Rant (Meinsberg)

Benchmarking the performance of a Peptide and DNA functionalized gold nanoparticle array for nanoplastic sensing // Guilherme Lopes (Jena)

Nucleic Acid–Directed Plasmonic Nanoparticle Biosensors: a review with a focus on food safety // Enrico Ferrari (Lincoln)

Poster pitch talks // Olesia Petrova

LUNCH & POSTER SESSION

14:00 Session 3 // Enrico Ferrari

UV Laser Crosslinking Reveals Expanded DNA-CTCF Interaction Landscape // Tino Schenk (Jena)

Photochemistry in the Origins of Life // Corinna Kufner (Jena)

Designer DNA via MOPED // Andrew Pike (Newscastle)

15:15 COFFEE BREAK

15:45 Session 3a // Juewen Liu

Down-and-up: Towards self-assembled electronics and optics by combining DNA bottom-up assembly with top-down microfabrication // Jussi Toppari (Jyväskylä)

Charge Transport in DNA: From Fundamental Insights to Ultra-Sensitive Detection // Danny Porath (Jerusalem)

3D Biofabricated DNA-Carbon Nanotube Nanodevices for Hybrid Nanoelectronics // Iman Elbalasy (Leipzig)

17:00 Excursion // Hike to Ernst Haeckel Monument

19:00 POSTER & BEER (& BARBECUE)

SATURDAY, MAY 9, 2026

Leibniz IPHT, Campus Beutenberg (Bus 10 leaves 8:42 a. m. downtown)

9:00 Session 4 // Andrew Pike

Fluorescent DNA templated metal clusters - Identification of single emitters // Uwe Pliquett (Heiligenstadt)

DNA origami based nanoantenna for enhanced fluorescence detection of microRNA // Milagros Montemurro (Fribourg)

Modulating Structural Permeability in DNA origami Nanocarriers // Merle Scherf (Leipzig)

10:15 COFFEE BREAK

10:45 Session 5 // Jussi Toppari

Structure-dependent nuclease-DNA origami interactions control limited cleavage of folded DNA nanostructures // Tanveer Ahmed (Leeds)

Stacked Wireframe DNA Origami: Design and Synthesis of Multi-Level Nanostructures // Eugen Czeizler (Bucharest)

DNA Origami for multi-functional optomechanical and plasmonic assemblies // David Daniel Ruiz Arce (Prague)

12:00 END & LUNCH

LOCATIONS

LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY

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0049 3641 206-304 (Office)
0049 3641 206-371 (Conference Desk)

wolfgang.fritzsche@leibniz-ipht.de

www.biophotonics4future.com/dna2026/

www.leibniz-ipht.de

DEL.CORAZóN

Venue Get-Together on Thursday May 7, 2026

Markt 2, 07743 Jena

www.delcorazon.de

ZUR NOLL

Restaurant and hotel

Oberlauengasse 19, 07743 Jena

www.zurnoll.de

TALKS

01 **DNA-Based Constitutional Dynamic Networks and Transient Dissipative Reaction Circuits** // Itamar Willner (Jerusalem)

02 **Fundamental studies of SELEX: from thermodynamics to kinetics** // Juewen Liu (Waterloo)

03 **DNA-programmed assembly of bispecific agents targeting receptor pairs on cancer cells** // Oliver Seitz (Berlin)

04 **Electroactuated DNA Origami Nanolevers Enable Molecule Friction Sensing of Protein Conformational Changes** // Ulrich Rant (Meinsberg)

05 **Benchmarking the performance of a Peptide and DNA functionalized gold nanoparticle array for nanoplastic sensing** // Guilherme Lopes (Jena)

06 **Nucleic Acid–Directed Plasmonic Nanoparticle Biosensors: a review with a focus on food safety** // Enrico Ferrari (Lincoln)

07 **UV Laser Crosslinking Reveals Expanded DNA-CTCF Interaction Landscape** // Tino Schenk (Jena)

08 **Photochemistry in the Origins of Life** // Corinna Kufner (Jena)

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10 **Down-and-up: Towards self-assembled electronics and optics by combining DNA bottom-up assembly with top-down microfabrication** // Jussi Toppari (Jyväskylä)

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18 **DNA Origami for multi-functional optomechanical and plasmonic assemblies** // David Daniel Ruiz Arce (Prague)

DNA-Based Constitutional Dynamic Networks and Transient Dissipative Reaction Circuits: From Basic Concept to Applications

Itamar Willner

Institute of Chemistry, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

Within the past eight years, we developed the topic of dynamic DNA networks that become a paradigm in DNA nanotechnology. This includes the assembly of DNA-based constitutional dynamic networks (CDNs) and transient, dissipative reaction circuits. These dynamic DNA frameworks mimic functions of complex natural biological circuits and find growing interest for different catalytic, biomedical, new adaptive materials, assembly of protocells (synthetic cells) and dictated native cell function applications. While the topic could be covered by a comprehensive course in Synthetic Biology, Systems Chemistry and Systems Biology, a short summary of the concepts and applications will be introduced:

1. The concepts of constitutional dynamic networks (CDNs) and dissipative, transient DNA circuits will be addressed. Their triggering by fuel strands, G-quadruplexes, aptamer-ligand and light will be introduced. The adaptive, hierarchically adaptive and feedback-driven operation is discussed.
2. Application of CDNs and dissipative circuits for operation of biocatalytic cascades and their application of dynamic, temporal, control of fibrinogenesis will be introduced.
3. Switchable stiffness properties of dynamic DNA hydrogels, their use for controlled drug release and the transient temporal control of optical properties of nanoparticles through DNA-driven dynamic aggregation will be demonstrated.
4. Dynamic, autonomous, gene therapy paradigms for cancer therapy will be introduced.
5. Transient, temporally light/pH-modulated phase-separated microdroplet coacervates as protocell assemblies will be discussed. Moreover, the integration of transient CDNs onto cell membranes for signaling cell migration, proliferation and apoptotic functions will be introduced.

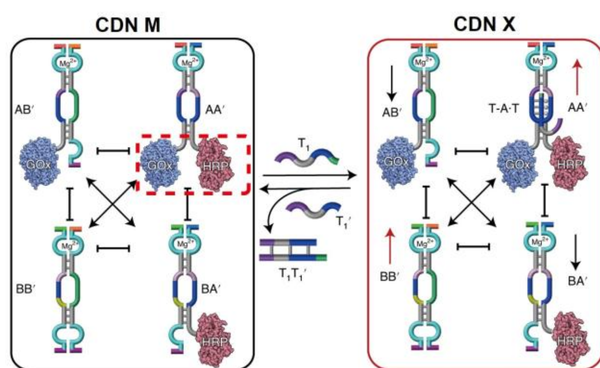


Fig. 1

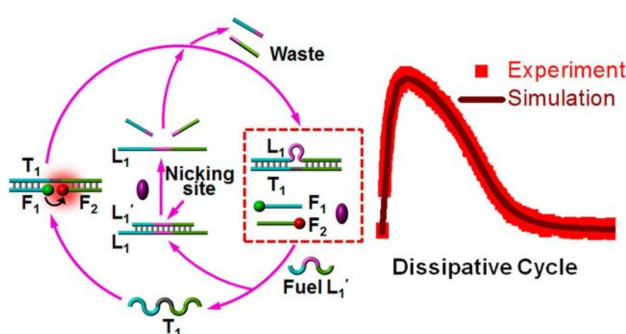


Fig. 2

Fig. 1: Schematic reconfiguration of constitutional dynamic networks for controlling biocatalytic cascades.
Fig. 2: Schematic triggering of dissipative, transient DNA circuits.

[1] L. Yue, et al. J. Am. Chem. Soc. 2020, 142 (52), 21577–21594
[2] C. Wang, et al. Nat. Catal. 2020, 3, 941–950
[3] N. Lin, et al. J. Am. Chem. Soc. 2024, 146 (30), 20685–20699
[4] Y. Qin, et al. J. Am. Chem. Soc. 2025, 147 (19), 16141–16153
[5] N. Lin, et al. J. Am. Chem. Soc. 2025, 147 (38), 34292–34302

Fundamental studies of SELEX: from thermodynamics to kinetics

Juewen Liu[1], Yuzhe Ding[1]

[1] Department of Chemistry, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada

DNA aptamers have emerged as versatile molecular recognition elements for applications in biosensing and drug delivery due to their high specificity and affinity toward a wide range of targets. Capture-SELEX refers performing aptamer selection by immobilization of a DNA library via hybridization to a capture strand. Capture-SELEX combined with deep sequencing allows quantitative study the SELEX process with fundamental understandings. In this talk, I will discuss our recent efforts to improve the efficiency and outcome of aptamer selection by systematically investigating key experimental parameters that govern aptamer evolution. We examine how target concentration, incubation time, pH, and ionic strength interact to influence selection pressure and binding performance.

Using nucleobase and nucleosides as targets, we have studied the effect of target concentration and established the relationship of target concentration and aptamer affinity.[1] At the same time, the lowest target concentration used cannot be smaller than the K_d of the best aptamers. Using ampicillin as a target, we discovered the effect of incubation time due to the kinetic difference of aptamer release. High affinity aptamers might be poorly enriched due to a kinetic disadvantage. By simply extending the incubation time, high affinity aptamers can be rescued (Fig. 1).[2] Using dopamine as an example, we discuss the effect of negative selections. Using kanamycin as a target, we discovered the effect of pH and also the library capture efficiency. These studies collectively enriched our fundamental understanding of SELEX. Using this method, aptamers for over 100 targets have been isolated in our lab in the last 5 years.

Fig. 1

Fig. 1: Two aptamers for ampicillin that are differ only by three nucleotides and their enrichment under different target concentration and incubation time conditions.

[1] Y. Ding, J. Liu, J. Am. Chem. Soc. **2023**, 145, 7540–7547.
[2] Y. Ding, Y. Heng, K.-Y. Wong, Q. Chen, J. Liu, Angew. Chem. Int. Ed. **2026**, 65, e14445.

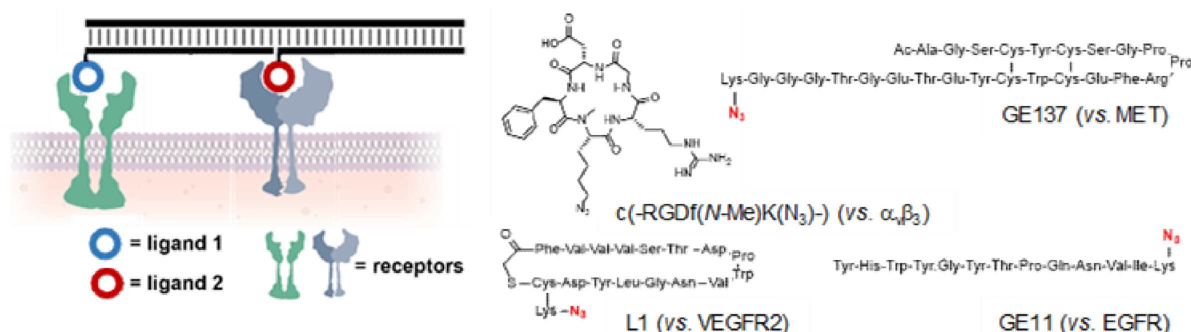
DNA-programmed assembly of bispecific agents targeting receptor pairs on cancer cells

Oliver Seitz[1], Pritam Ghosh[1], Huyen Dinh[1]

[1] Institute of Chemistry, Humboldt University Berlin, Brook-Taylor-Straße 2, 12489 Berlin, Germany

Bispecific agents have the potential to target tumor cells more effectively and with greater precision than their monospecific counterparts. Following the rapid development of monospecific antibodies, therefore, bispecific antibodies are gaining traction in clinical applications. However, developing bispecific antibodies presents substantial challenges. Their high molecular weight limits tissue penetration. Importantly, the functional performance of bispecifics is highly dependent on the spatial organization of their targets. It is, therefore, disadvantageous that the distances between an antibody's binding domains cannot be freely adjusted. Conversely, DNA nanostructures enable control at the nanometer-scale over the spacing and orientation of attached functional units. Serving as programmable scaffolds, DNA nanostructures allow systematic explorations of receptor arrangements and valency effects that are difficult to access using protein-only designs. However, DNA nanostructure-based platforms also present new challenges. The scaffolds have a molecular weight comparable to, and mostly even higher than that of antibodies. Therefore, tissue distribution is expected to remain problematic. Furthermore, large-scale manufacturing is challenging.

Recognizing the importance of low molecular weight, we explore double stranded nucleic acid complexes much smaller than previously used DNA nanostructures.[1], [2] We investigated the use of readily assemblable DNA duplexes to program bispecific targeting of specific cell types. Unlike previous bispecific agents, we exploit the potential of peptide-based high affinity binders of cell surface proteins used in diagnostics/therapeutics. Systematic spatial screening revealed the optimal distance between two (cyclo)peptides required for the selective recognition of cells expressing unique receptor combinations. We observed significant differences in the distance-affinity landscape when targeting of the VGFR2 / $\alpha_V\beta_3$ receptor system on HUVECs in comparison to EGFR / MET on A549 cells. The DNA-programmed bispecific binders demonstrated specificity and efficient internalization into target cells. Auristatin-loaded DNA enabled a selective targeting of cytotoxic payload. Flow cytometry of mixed cell populations indicated that the cell-type specificity is encoded by bispecific presentation of cyclopeptides on the DNA scaffolds. Both targeting and internalization are required for cytotoxic activity, while conjugation with DNA effectively masks the cytotoxic payload until internalization occurs specifically.



[1] P. Ghosh, H. Dinh, A. Koçak, A. K. Homer, P. Bou-Dip, S. Schlicht, O. Seitz (2025). Angew Chem In. Ed, 64, e202514237.
[2] P. Ghosh, H. Dinh, O. Seitz (2026). RSC Chem Biol, 7, 200–207.

Electroactuated DNA Origami Nanolevers Enable Molecular Friction Sensing of Ligand-Induced Protein Conformational Changes

Ulrich Rant[1,2,3], Pablo Porragas Paseiro[3,4], Lukas Aufinger[3], Alfred Kick[1], Tereza Jahodová[3,5], Veronica Hamer[3], Wouter Engelen[3]

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[2] *TU Dresden, Germany*
[3] *Bruker Biosensors, Munich, Germany*
[4] *TU Darmstadt, Germany*
[5] *Ludwig Maximilians Universität, Munich, Germany*

Ligand binding often shifts protein conformational equilibria, yet screening-compatible methods capable of directly resolving binding-induced structural changes remain limited. We present a molecular friction sensing approach based on electrically actuated DNA origami nanolevers for quantitative detection of protein hydrodynamic size and conformational rearrangements.

Proteins are covalently tethered to rigid 4-helix bundle DNA origami levers anchored to microelectrodes. Upon application of an alternating electric potential, synchronized nanolever oscillations are monitored by electrically triggered time-correlated single-photon counting. The switching velocity reflects rotational diffusion and hydrodynamic drag, enabling sensitive readout of protein size at the electrode interface.

Across a panel of proteins (9–240 kDa), differential oscillation velocity correlates linearly with hydrodynamic radius. Ligand-induced conformational changes were resolved with sub-Angstrom sensitivity. Functionally distinct ligand classes and dose-dependent transitions were clearly discriminated, and screening of carbonic anhydrase inhibitors revealed ligand-specific bidirectional conformational responses independent of binding affinity.

This electroanalytical platform bridges affinity measurements and structural characterization, enabling high-resolution, screening-compatible detection of binding-induced conformational changes directly at electrode surfaces.

Benchmarking the performance of a Peptide and DNA functionalized gold nanoparticle array for nanoplastic sensing

Guilherme Lopes[1,2], Florian Seier[1], Menbere Mekonnen[1], Julia Böke[1], Jyothi B. Nair[1], Carlos Marques[2], Wolfgang Fritzsche[1]

[1] Leibniz Institute of Photonic Technology, Albert-Einstein-Straße 9, 07745 Jena, Germany

[2] CICECO – Aveiro Institute of Materials, Physics Department, University of Aveiro, Aveiro 3810-193, Portugal;

The most common optical methods for microplastic detection are vibrational spectroscopy techniques, such as Raman or Fourier-transform infrared spectroscopy, which provide reliable chemical identification through the fingerprint spectra associated with the different plastics [1]. While this is an effective and consolidated approach, since vibrational spectroscopy requires highly expensive equipment, especially when considering nanoplastic particles, there is still interest in the development of newer sensing platforms [2].

Recently, newer biomolecular interactions have been reported between nanoplastics and specific peptides, as well as DNA aptamers and oligonucleotides [3], [4], [5]. The basis of these interactions is surface adsorption modulated by hydrophobicity, charge, π–π interactions, hydrogen bonding and metal ions. This proposal aims to combine both peptide and DNA receptors by integrating them into a localized surface plasmon resonance (LSPR) sensor platform. LSPR is described by the collective oscillations of electrons present in metallic nanostructures, typically gold, when excited by an electromagnetic field. This oscillation produces, in the surroundings of the particles, a localized field that is highly sensitive to changes in refractive index. These characteristics make the advantages of the LSPR its label-free and real-time detection, as well as high sensitivity and compact device architecture[6], [7].

Although literature indicates that DNA aptamers exhibit polymer-class selectivity, it also indicates limited discrimination between different polymer types. Thus, a multiplexed LSPR sensor, which enables direct comparison of peptide and DNA performance under similar conditions. The platform consists of a gold nanoparticle array where distinct sections are functionalized with either polymer-specific peptides or DNA aptamers/oligonucleotides, facilitating simultaneous assessment of affinity, selectivity, and LSPR response for at least two different nanoplastics and other related targets.

References

[1] G. Lopes, A. J. Fernandes, A. Carvalho, and C. Marques, 'Development of a low-cost Raman spectroscopy platform for high-throughput analysis', in 29th International Conference on Optical Fiber Sensors, J. L. Santos, M. L.-A. Sainz, and T. Sun, Eds., SPIE, 2025, p. 1363977. doi: 10.1117/12.3062778.

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[3] M. Zandieh, K. Patel, and J. Liu, 'Adsorption of Linear and Spherical DNA Oligonucleotides onto Microplastics', Langmuir, vol. 38, no. 5, pp. 1915–1922, Feb. 2022, doi: 10.1021/acs.langmuir.1c03190.

[4] M. Zandieh, X. Luo, Y. Zhao, C. Feng, and J. Liu, 'Selection of Plastic-Binding DNA Aptamers for Microplastics Detection', Angew. Chem. Int. Ed., vol. 64, no. 11, Mar. 2025, doi: 10.1002/anie.202421438.

[5] H. Woo et al., 'Sensitive and specific capture of polystyrene and polypropylene microplastics using engineered peptide biosensors', RSC Adv., vol. 12, no. 13, pp. 7680–7688, Mar. 2022, doi: 10.1039/d1ra08701k.

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[7] S. Kastner, M. Urban, A.-K. Dietel, A. Csáki, and W. Fritzsche, 'Cost-Effective and Robust Multispectral Light-Emitting Diode Device for the Readout of Plasmonic Microarray Sensors', Adv. Photonics Res., vol. 4, no. 2, Feb. 2023, doi: 10.1002/adpr.202200252.

Nucleic Acid–Directed Plasmonic Nanoparticle Biosensors: a review with a focus on food safety

Enrico Ferrari[1]

[1] University of Lincoln, Brayford Pool, LN6 7TS, Lincoln, United Kingdom

Nucleic acids have emerged as versatile building blocks in biosensor design, underpinning highly sensitive detection through hybridization, structural switching, and catalytic mechanisms. When integrated with plasmonic readouts, these systems enable robust optical transduction that can be implemented in portable, low-cost formats.
This review highlights recent advances in nucleic acid–mediated plasmonic biosensing, focusing on strategies that transform conventional assays into sensitive, user-friendly platforms suitable for on-site analysis.

We survey a range of mechanisms underlying signal generation, including colorimetric detection via nanoparticle aggregation, plasmonic modulation driven by nanomaterial growth or etching, and dynamic structure-switching nanostructures. Advances in localized surface plasmon resonance (LSPR) sensing on chip-based architectures functionalized with nucleic acids are also discussed.
Particular attention is given to how modern nucleic acid amplification and editing techniques, such as CRISPR-based systems, isothermal amplification, and enzyme-free circuits, enhance signal transduction and broaden target scope.
In addition to summarizing state-of-the-art technologies, this review explores the emerging role of artificial intelligence and computational design in optimizing nucleic acid-based biosensors, from sequence selection to structural prediction and performance evaluation.

As a case study, we emphasize the specific challenges and opportunities in food safety applications, where rapid, low-cost, and portable diagnostics are critically needed. The food sector, unlike healthcare, operates under stringent cost constraints, making it an ideal testbed for disruptive biosensing technologies that combine molecular precision with practical deployability.

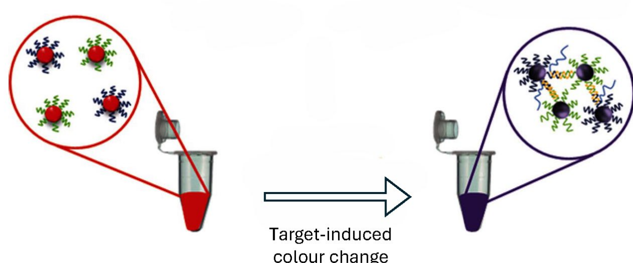

Fig. 1

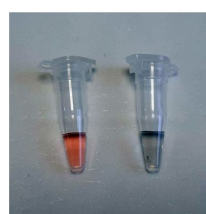

Fig. 2

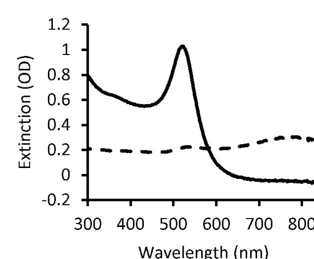

Fig. 3

Fig. 1: Schematic of target-induced colour change in a suspension of DNA-functionalised gold nanoparticles (adapted from [1]).
Fig. 2: Comparison of dispersed and aggregate gold nanoparticle suspensions (adapted from [2]).
Fig. 3: Extinction spectra of the suspensions in Fig. 2 (adapted from [2]).

[1] L. Tang and J. Li (2017). ACS Sens, 2 (7), 857–875.
[2] E. Ferrari (2023). Biosensors, 13 (3), 411.

UV Laser Crosslinking Reveals Expanded DNA-CTCF Interaction Landscape

Clara Stanko[1,2], S. Fischer[1,2], G. Özcan[1,2], Sven Stengel[3] and Tino Schenk[1,2]

[1] Department of Hematology/Oncology, Clinic of Internal Medicine II, Jena University Hospital, Jena, Germany
[2] Institute of Molecular Cell Biology, Center for Molecular Biomedicine Jena (CMB), Jena University Hospital, Jena, Germany
[3] Department of Neuropediatrics, Jena University Hospital, Jena, Germany.

CTCF is a crucial architectural protein that organizes eukaryotic genomes through DNA binding and chromatin loop formation. However, conventional formaldehyde-based ChIP-seq preferentially captures stable protein-DNA interactions, biasing detection toward long-range chromatin architecture and topologically associated domain (TAD) boundaries. In this study, we used ultraviolet (UV) laser crosslinking combined with ChIP-seq to comprehensively map stable and transient DNA-CTCF interactions across the genome.

UV ChIP-seq identified 38,706 CTCF binding sites in K-562 cells, with 70% previously undetected by standard formaldehyde fixation. Comparative analysis revealed distinct binding patterns: UV-specific sites concentrated at active promoters and enhancers within short-range chromatin loops (<200 kb), while formaldehyde preferentially detected CTCF at TAD boundaries and long-range loops. Integration of both methodologies achieved >90% coverage of active promoters genome-wide. *De novo* motif analysis uncovered noncanonical CTCF binding configurations at UV-specific sites, suggesting alternative DNA-binding modes beyond the canonical zinc-finger recognition sequence.

Alternative chromatin fragmentation using micrococcal nuclease further revealed additional UV-exclusive sites, indicating that fixation chemistry and fragmentation strategy, determines the DNA-CTCF interaction landscape captured. These findings demonstrate that complementary crosslinking strategies are essential for comprehensive characterization of transcription factor-DNA binding dynamics.

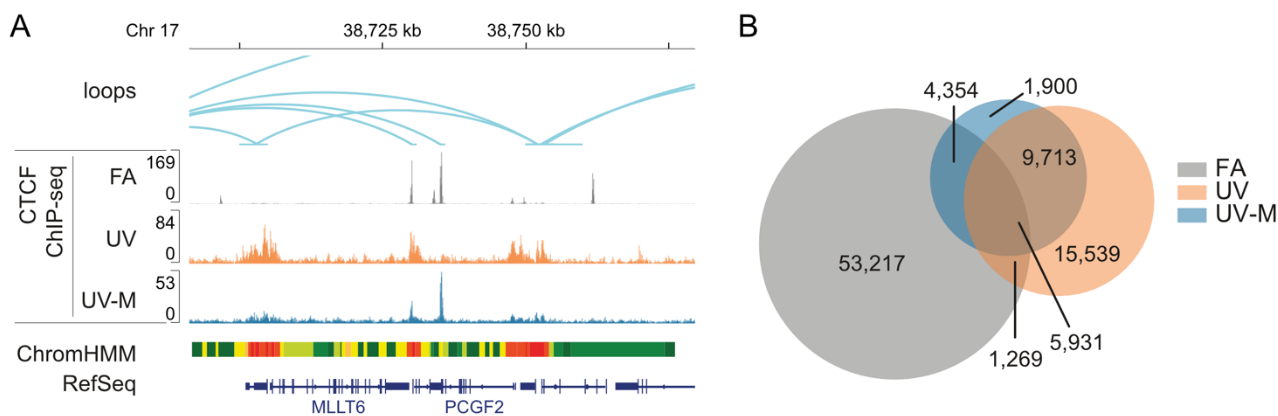

Figure 1: (A) Example of representative CTCF binding sites in K562 cells detected by formaldehyde (FA) ChIP-seq (grey), UV ChIP-seq (orange) and UV-MNase (UV-M) ChIP-seq (blue). An overlay of three replicates and chromatin loops detected by Hi-C and chromatin state annotations from a multivariate Hidden Markov Model (ChromHMM) are shown. **(B)** Venn diagram showing the overlap between CTCF binding sites identified by FA ChIP-seq, UV ChIP-seq and UV-M ChIP-seq.

[1] Stanko, C. et al. bioRxiv, 2025.05. 12.653382.

Photochemistry in the Origins of Life

Corinna L. Kufner[1]

[1] Leibniz Institute of Photonic Technology, Albert-Einstein-Straße 9, 07745 Jena, Germany

The chemical assembly of essential biomolecules, such as DNA, RNA, lipids or peptides from simple starting materials in realistic early Earth environments is one of the key challenges in answering the question of how life originated. Solar radiation is often missing from these considerations, even though is was abundant on the surface of the early Earth. In particular, ultraviolet (UV) radiation has the ability to disrupt chemical reactions, but also to open up new reaction pathways. Recent evidence suggests that solar radiation probably played a key role as a selection pressure in the origin of life.
This talk will provide a broad overview of the current challenges in the interdisciplinary field of *origins of life* research and outline the potential of photochemistry in this endeavor.

Large Scale Designer DNA via MOPED- **M**ultiplication of **O**ligos using **P**olymerase **E**xtension and **D**igestion

Morag R. Grierson[1,2], Charlotte Hepples[2], Eimer M. Tuite[2] and Andrew R. Pike[1,]

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[2] NunaBio Ltd., The Biosphere, Draymans Way, Newcastle Helix Newcastle Upon Tyne, NE4 5BX

Oligos have been commercially synthesised using **phosphoramidite** chemistry for over 40 years.[1] An increased demand for oligos for use in therapeutics, DNA-based materials, DNA origami etc., has challenged these ageing synthetic approaches.

Phosphoramidite chemistry produces large volumes of toxic waste, supplies only low yields of oligos > 100 bps and has difficulty in producing homopolymers.[2]

More recent developments have focused on **enzymatic** approaches, which due to their relative infancy still face many drawbacks including inaccurate sequence production, slow muti-step processes and high running costs. therefore current enzymatic methods are impractical for the large-scale production of DNA-oligos.[3]

Short **DNA-oligos** cannot be amplified by standard PCR methods and so an alternative approach is required. Here we describe **MOPED** - a versatile synthetic approach which combines self-priming enzymatic extension,[4-6] with restriction enzyme digestion[7] to give multiple copies of a target oligo.

Our investigations of the DNA folding process without denaturing conditions are also discussed like a self-assembly of DNA origami even at room temperature. This would be also promising for a one-pot folding of DNA and thermo-sensitive biomolecules like enzymes.

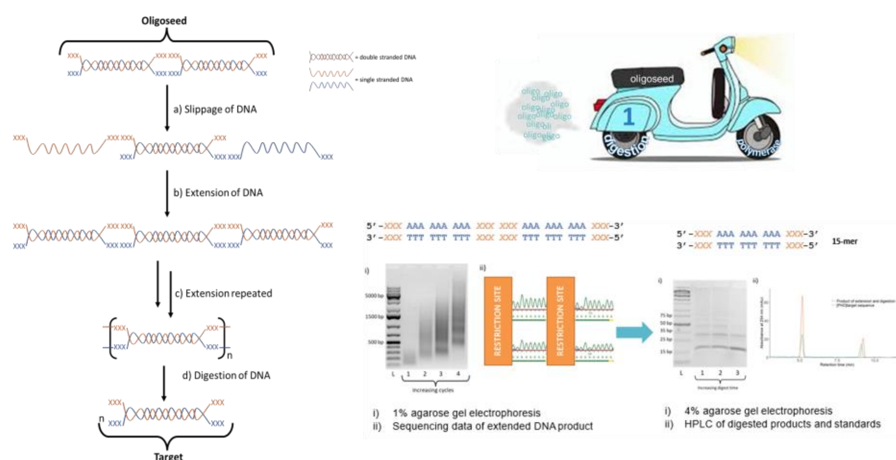

Fig. 1: Overview of the MOPED approach to designer DNA for oligo synthesis

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*[2] A. Hoose, R. Vellacott, M. Storch, P. S. Freemont and M. G. Ryadnov, Nat. Rev. Chem., 2023, **7**, 144–161.*
*[3] J. B. Boulé, F. Rougeon and C. Papanicolaou, Journal of Biological Chemistry, 2001, **276**, 31388–31393.*
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Down-and-up: Towards self-assembled electronics and optics by combining DNA bottom-up assembly with top-down microfabrication

J. Jussi Toppari

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Molecular electronics and molecular-scale optics, particularly plasmonics, have long been envisioned as key drivers of the next major technological advances. DNA has emerged as one of the most versatile and promising molecular platforms for nanoscale fabrication [1], including applications in electrical and plasmonic systems [2]. Owing to its intrinsic self-assembly properties, DNA enables fully parallel fabrication, allowing the simultaneous production of vast numbers of devices. However, as self-assembly typically occurs in solution, effective integration with top-down fabrication methods is required—at minimum to position the assembled structures on substrates. More importantly, the direct integration of bottom-up self-assembly with top-down processing during fabrication offers significantly expanded capabilities and versatility.

We have developed methods to trap and electrically connect individual molecular-scale devices to external circuitry [2,3]. This approach has enabled the investigation of charge transport in various single DNA nanostructures, including single-electron transistor architectures [3]. In the field of nanoscale optics, we have introduced DNA-assisted lithography (DALI), a fabrication strategy that combines DNA origami with conventional top-down microfabrication techniques. This method enables the realization of high-quality plasmonic nanostructures with feature sizes below 100 nm and precisely defined geometries [4]. As a proof of concept, we fabricated optical bowtie antennas exhibiting tunable plasmonic resonances within the visible spectral range.

To further advance optical component fabrication, we have pursued the development of self-assembled metasurfaces by organizing DNA origami structures into extended surface lattices. These nanostructured assemblies offer spatial precision comparable to electron-beam lithography while avoiding the inherent limitations of serial, time-consuming, and costly patterning processes. To date, large-area, highly ordered DNA origami lattices have predominantly been achieved on ultra-smooth substrates, such as mica or supported lipid bilayers [5], which are generally incompatible with standard microfabrication workflows. To address this limitation and enable subsequent processing steps — such as DALI or BLIN [4] — we have demonstrated large-scale assembly of two-dimensional fishnet-type lattices directly on silicon substrates using cross-shaped DNA origami building blocks (Seeman tiles) [6].

Thus far, we have achieved polycrystalline lattice coverage over large areas with average domain diameters of approximately 2 µm, as well as single-crystalline domains up to 5.6 μm^2 comprising 670 interconnected DNA origami units. Furthermore, we have developed a method to fabricate rolled DNA origami lattices, forming tubular geometries [7]. The successful implementation of DNA origami lattice assembly on silicon substrates opens new avenues for scalable, DNA-based nanofabrication compatible with established semiconductor processing technologies.

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Charge Transport in DNA: From Fundamental Insights to Ultra-Sensitive Detection

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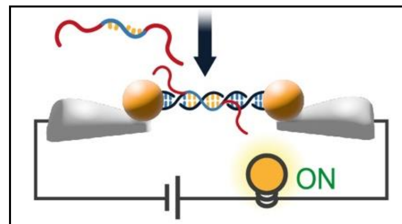

The ability to recognize and manipulate the DNA double helix opens exciting opportunities for molecular electronics. Our recent work (Nature Nanotechnology, 2020) demonstrated a breakthrough in measuring charge transport in DNA using a unique configuration. This discovery is not only fundamental for understanding electrical properties in DNA but also holds significant implications for molecular electronics as a whole.

Beyond its intrinsic scientific value, this insight lays the foundation for the development of ultra-sensitive DNA and RNA detection methods. Such advancements are particularly crucial for early cancer diagnosis, pathogen identification, emergency medicine, and pandemic preparedness, as seen in the case of COVID-19.

In this lecture, I will present our approach to probing charge transport in DNA and discuss how we are leveraging this phenomenon for next-generation molecular detection technologies.

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3D biofabricated DNA-carbon nanotubes nanodevices for hybrid nanoelectronics

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The use of DNA-templated approaches for the fabrication of ultra-scaled semiconductor electronics is emerging as a powerful strategy enabling precise nanoscale patterning beyond the limits of conventional lithography. Among potential channel materials, single-walled carbon nanotubes (SWCNTs) possess exceptional electronic properties that make them highly promising for aggressively scaled, high-performance transistors. Indeed, numerous studies have demonstrated carbon nanotube field-effect transistors (CNTFETs) exhibiting outstanding device performance [1]. However, the realization of the full potential of CNTs in transistors is extremely challenging as evenly spaced semiconductor channels at sub 10 nm pitch (spacing between two adjacent channels within an individual transistor) are required. This is smaller than the fabrication feasibility of the existing nanolithography technology and has not been achieved so far. The European-funded project 3D-BRICKS, aims to overcome the nanofabrication limit by using 3D DNA nanostructures as a template [2]. The DNA template is designed with the capability of integrating CNT arrays with a uniform pitch in addition to metallic nanoparticles [3]. Toward this aim, we employed DNA origami to fabricate nanotrenches (10 nm width x 60 nm length) with orthogonal capture strands to anchor DNA-functionalized CNTs and metal nanoparticles at specific sites and orientations (Fig1A). Via specific binding sequences extending externally from the sides, we developed specific multimerization of 2 and 3 nanotrenches in parallel to allow the assembly of parallel arrays of CNTs. TEM images showed efficient binding of CNTs inside nanotrench monomers and multimers (Fig 1B). Elongated nanotrench trimers were also assembled via specific longitudinal multimerization of nanotrench monomers, they function as channels hosting CNTs inside as shown in figure 1C. Currently we are investigating a design developed to allow the metal contacts on single CNTs inside the trenches. In this design two trimers bind vertically via specific binding sequences. While the lower trimer possesses only the CNT capture strands, the upper one shall carry additional capture strands to place metal nanoseeds above the bound CNT as illustrated in figure Fig. 1D. When growing metal on the bound seeds, the nanotrenches adjacent to the CNT get filled such that two nanoelectrodes will extend on the CNT. Parallel multimerization of several elongated nanotrenches will allow to form parallel arrays of contacted CNTs. Eventually we aim to build 3D geometries of CNTs-loaded origami channels connected horizontally and vertically. This will enable the creation of a new generation of transistors with unprecedented size, performance, and low production costs.

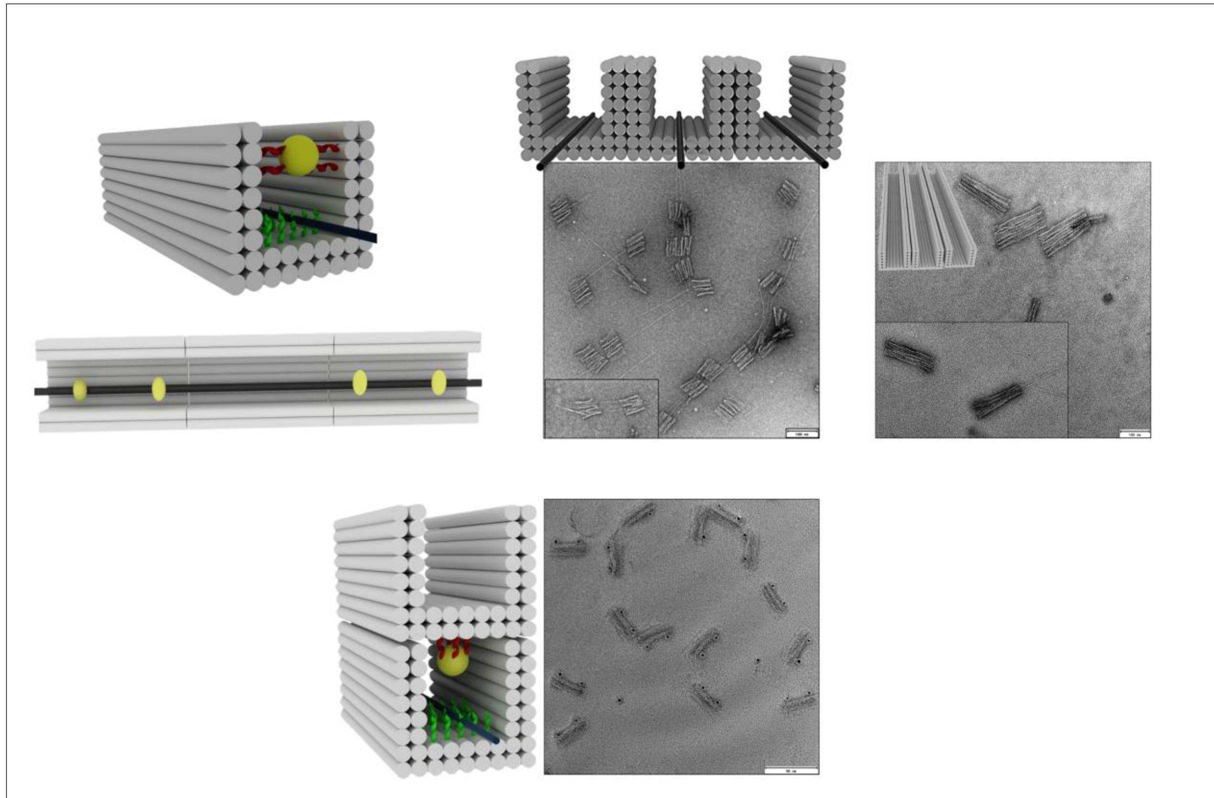

Figure 1. **A**: Design of DNA origami nanotrench with orthogonal capture strands for anchoring CNTs and metal nanoparticle. **B**: CNTs binding to the bottom of 3 nanotrenches connected laterally. **C**: Assembly and CNTs binding to 3 trimers. **D**: Design of vertically bound nanotrenches allowing CNTs-metal nanocontact, the TEM image shows capture of two gold nanoparticles. Scale bar: 100 nm in B and C; 90 nm in D.

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Acknowledgements. *This work is funded by EIC (Project 101099125 — 3D-BRICKS).*

Fluorescent DNA templated metal clusters - Identification of single emitters

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The quantitative investigation of dynamic phenomena and the quantum properties of metal-DNA clusters [1] (Me:DNA) requires analysis at the single emitter level. It is assumed that Me:DNA possesses only one fluorescent center, formed by the quantum properties of the metal cluster (consisting of 4 to 20 atoms), thus functioning as a single emitter [2].

In contrast to conventional studies in suspension, where a multitude of emitters are present in various configurations and orientations, our measurements focus on single emitters. This allows for clear statements about statistical distributions of energy states and a more precise verification of theoretical assumptions regarding the electronic landscape and the quantum properties of specific Me:DNA clusters.

Here, we use single stranded DNA (5`-TGC CTT TTG GGG ACG GAT A - 3`, 19bAg) templating a silver cluster.

Particular attention is paid to the dynamics of conformational changes in Me:DNA and its optical switching behavior through energy transfer under defined environmental conditions.

The results of our experiments are primarily intended to provide insights into the potential of Me:DNA for quantum applications, particularly with regard to intracellular quantum sensing.

The fluorescence of Me:DNA clusters is highly dependent on the environment, making it necessary to detect and track even dark conglomerates. We used GelRed to stain the nucleic acids of the DNA. Fluorescence lifetime is used to differentiate between GelRed and cluster fluorescence, which, at least for some DNA-sequences, share the same wavelength range. This allows for the unambiguous identification of individual Me:DNA clusters.

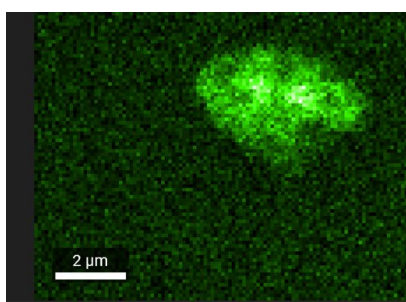

Fig.1

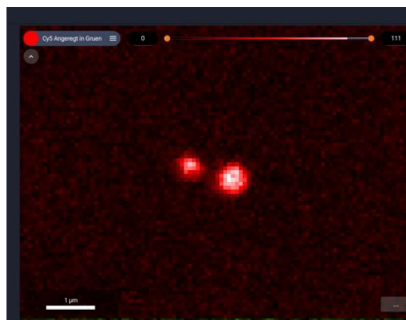

Fig.2A

Fig.2B

Fig. 1: Ag:19b – Clusters and individual emitters can only be resolved at a sufficient distance, as targeted switching is not possible. (Silver as metal organized by 19-base ssDNA, distance 0.9 µm)

Fig. A: Ag:19b (left) and ssDNA19b stained with GelRed, B: only the short fluorescence lifetime (GelRed) is shown.

This work is supported by the Federal Ministry of Research, Technology and Space (BMFTR), Program: Wissenschaftliche Vorprojekte (WiVoPro): Photonik und Quantentechnologien, FKz. 13N16759, QC4EP.

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DNA origami based nanoantenna for enhanced fluorescence detection of microRNA

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Liquid biopsies provide valuable clinical information through the analysis of biomarkers present in body fluids, such as peripheral blood samples [1]. Among the various classes of biomarkers, microRNAs (miRNAs) which are short, non-coding RNA molecules (19–25 nucleotides in length), play key regulatory roles in cancer progression [2]. Numerous miRNAs associated with cancer show strong promise as targets for liquid biopsy-based diagnostics. However, their detection remains challenging due to the need for high sensitivity and specificity. Moreover, quantitative and multiplexed analysis is essential to monitor changes in miRNA concentrations and identify specific disease expression patterns [3]. In addition, the direct detection of low-abundance analytes can be further hindered by low signal-to-background ratios. In this work, we propose plasmonic nanoantennas (NAs) designed to enhance the fluorescence-based detection of miRNAs. Plasmonic NAs are structures constituted of plasmonic metallic nanoparticles (NPs) that can intensify and localize electromagnetic fields enhancing the excitation and emission rate of a fluorophore placed in the proximity [4]. The construction of the proposed NA involved the synthesis and functionalization of metallic NPs and the precise attachment of these NPs to DNA origami to form a dimer NA structure. The NPs employed in this work are silver-coated gold nanorods (Au@Ag NRs), synthesized from gold nanorods (AuNRs) through a controlled overgrowth process with silver nitrate and ascorbic acid at 65 °C. The synthesized Au@Ag NRs (58 × 29 nm) were functionalized with thiol-modified T18 ss DNA oligonucleotides. DNA origami NAs were then assembled via hybridization between the T18-functionalized Au@Ag NRs and complementary A8 ssDNA strands protruding from the long-shaped DNA origami structure. First, the fluorescence enhancement was assessed using a DNA origami modified with a fixed ATTO680 dye in the center of the gap between two NPs and measuring single molecule fluorescence signals with wide-field microscopy. The results revealed that the dimer NAs achieved fluorescence enhancement factors up to 1000-fold, with an average value of 285±251. The strong fluorescence enhancement achieved by the plasmonic dimer NAs demonstrates their potential for highly sensitive miRNA detection. By modification of the DNA origami with capturing strand in the center of the gap, the designed NAs was further applied to the detection of 4 miRNAs associated to Acute Lymphoblastic Leukemia. The bioassay consists of the binding of the unlabeled analyte to the capturing strands, and the sequential detection of each miRNA by binding of a second imager strand labeled with the dye. The transient binding of the short imager strands (7-8 nt) to their complementary target in the hotspot are identified by fluorescent blinking bursts. This approach provides a promising platform for the development of liquid biopsy assays and improvement of cancer diagnostics.

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Modulating Structural Permeability in DNA origami Nanocarriers

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While most DNA origami–based drug delivery systems focus on transport of an attached cargo, we present an origami cage with a freely movable cargo that is trapped inside the cavity. However, due to their helix-based architecture, DNA origami nanocages are inherently flexible and permeable, making premature cargo leakage a central design challenge. Our system consists of a central hollow tube structure with a quadratic cross-section composed of a 10x10 array of parallel DNA helices. They are arranged in two layers (64 helices in total), forming a square lattice with a cavity measuring ~ 15x40 nm. The tube is sealed by two densely packed blocks, each composed of 10x10 parallel DNA helices (99 helices in total), also arranged in a square lattice. Cargo molecules are tethered inside the cavity via complementary ssDNA strands and after toehold mediated strand displacement they remain freely movable inside of the cavity. Systematic leakage analysis identified the tube–lid interface as the primary weak point. This interface is formed by protruding helices and 2-nt recessions/extensions that hybridize with complementary scaffold regions of the adjacent tube or lid helices.

However, oxDNA simulations revealed transient helix opening events at this interface, suggesting structural fluctuation as a major cause of permeability. Extending the overhang length significantly reduced interface fluctuations and markedly improved cargo retention.

To further modulate permeability, we tested inner and outer stabilization strategies: (i) thymidine-based UV crosslinking at the interface, (ii) electrostatic coating with poly(L-lysine)–PEG block copolymers, and (iii) subsequent glutaraldehyde crosslinking of the polymer shell. These approaches also showed a various positive influence on cargo retention.

This systematic analysis provides a modular toolbox to characterize and tune DNA origami permeability. Rather than solely engineering release mechanisms, our work highlights structural confinement as a critical and controllable design parameter in DNA origami–based drug delivery systems.

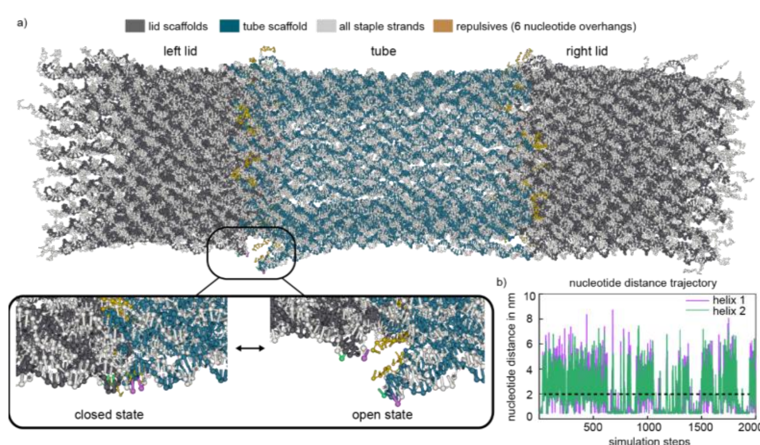

Fig. 1

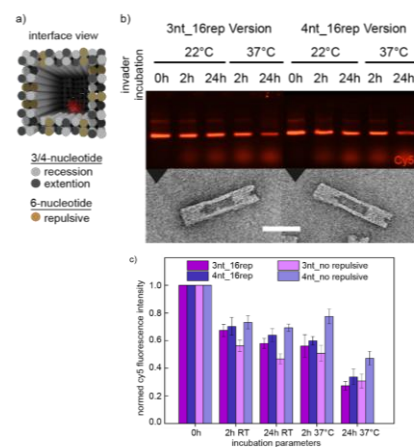

Fig. 2

Fig. 1: oxDNA simulation snapshot at 40°C of the nanocage, highlighting helix fluctuations.

Fig. 2: Strand displacement reaction and cargo retention in different cage versions.

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Structure-dependent nuclease-DNA origami interactions control limited cleavage of folded DNA nanostructures

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Folded DNA origami nanostructures differ markedly from linear double-stranded DNA in geometry and packing, so their architecture influences how nucleases act on them even when the catalytic mechanism remains unchanged [1]. We investigated how structural context affects specific and non-specific nuclease action by studying exonuclease III (Exo III) and mung bean nuclease (MBN) reaction on two widely used DNA origami designs: a two-dimensional Rothemund triangle and a three-dimensional six-helix bundle (6HB). Time-course exposure analysis using agarose gel electrophoresis and atomic force microscopy, determined that Exo III progressively trimmed DNA ends and ultimately induced full structural collapse in both designs, with collapse occurring on similar timescales for the 2D and 3D origami. In contrast, MBN selectively cleaved exposed single-stranded regions. In the triangular origami, this produced three discrete trapezoidal domains corresponding to the original Rothemund layout, whereas the compact 6HB remained largely intact, with only limited potential trimming at exposed or unpaired regions.

These observations indicate that features such as dimensionality, helix packing density and site accessibility (buried vs exposed) can modulate how folded DNA nanostructures respond to nucleases. Furthermore, our outcomes provide practical guidance for designing DNA origami with stability profiles suited to interfacing with biology and functional DNA nanotechnology applications.

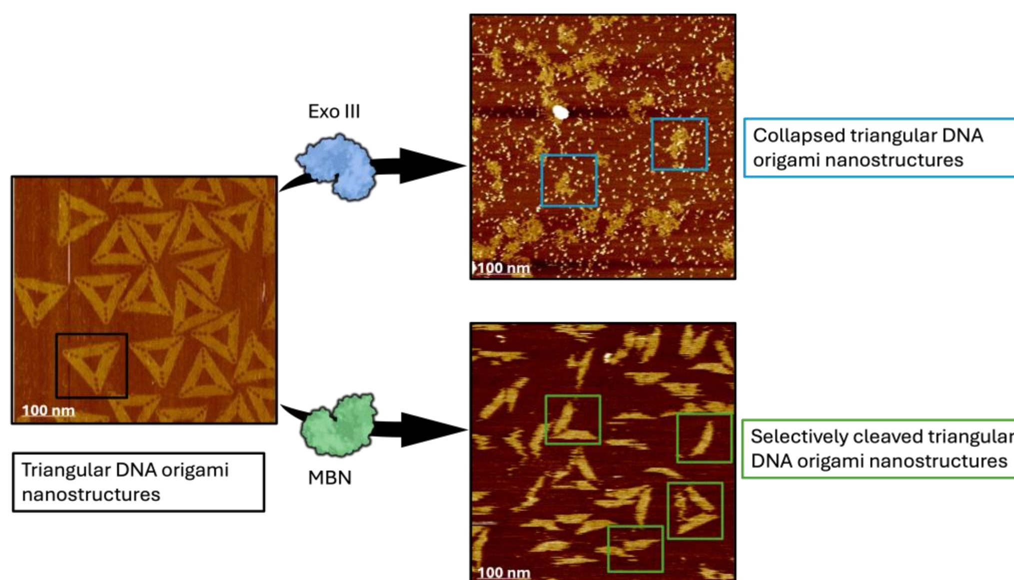

Fig. 1: AFM of triangular DNA origami after nuclease treatment. Exo III erosion yields collapsed triangles (left); MBN cleavage of exposed ssDNA regions produces discrete fragments (right).

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Stacked Wireframe DNA Origami: Design and Synthesis of Multi-Level Nanostructures

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Wireframe DNA origami enables the programmable construction of nanoscale structures by routing a single scaffold strand along the edges of a geometric mesh stabilized by short staple strands [1]. Algorithmic routing methods implemented in tools such as PERDIX and DAEDALUS allow the automated generation of complex wireframe architectures directly from arbitrary meshes [2,3]. While these approaches substantially expand the structural design space of DNA nanotechnology, most wireframe implementations focus on planar single-layer structures or closed polyhedral geometries [4]. The systematic integration of multiple wireframe layers into a single scaffolded architecture remains largely unexplored. **Here we address this challenge by introducing a computational and experimental framework for constructing vertically stacked wireframe DNA origami structures.**

We introduce **Multi-Level Wireframe DNA Origami (MLWDO)**, a new architectural paradigm in which partially overlapping two-dimensional wireframe layers are stacked and interconnected to form vertically organized DNA origami nanostructures. In MLWDO architectures, each layer corresponds to a planar wireframe mesh, while adjacent layers are connected through staple strands extending across levels. All layers share a single scaffold strand, resulting in an integrated nanostructure in which the scaffold traverses the entire multi-layer system. Conceptually, this strategy resembles layered fabrication approaches such as base-relief construction or additive manufacturing, where complex three-dimensional geometries emerge from the controlled stacking of planar components.

To enable the design of such architectures, we developed a computational framework that extends the PERDIX wireframe origami pipeline to multi-layer systems. Within this framework, the target architecture is decomposed into individual wireframe layers represented as planar meshes. The pipeline automatically invokes PERDIX to compute scaffold routing and staple sequences for each layer and subsequently integrates the resulting layer-level designs into a unified stacked structure through automated alignment and cross-layer connectivity generation.

The framework identifies suitable inter-layer connectivity points and generates cross-layer staple strands that link adjacent layers into a single integrated structure. These connective staples are produced by extending selected staple strands across layers using short nucleotide linkers that accommodate the vertical spacing between layers. The pipeline finally outputs the complete set of DNA sequences required for experimental implementation, including both standard staples and cross-layer connectors, thereby providing a direct output suitable for oligonucleotide synthesis.

To evaluate the feasibility of MLWDO structures, we designed and assembled prototype architectures based on a hexagonal wireframe geometry using the M13mp18 single-stranded DNA scaffold. In initial experiments, the scaffold sequence was divided into two halves to generate two independent hexagonal wireframe structures. Both designs folded successfully when assembled individually and also co-assembled within a single folding reaction.

Using cross-layer connective staples, we subsequently constructed vertically stacked assemblies containing multiple wireframe layers. Structures with up to three stacked layers assembled reliably, whereas designs incorporating a fourth layer exhibited reduced assembly quality and stability. These results demonstrate that vertically stacked wireframe DNA origami architectures can be realized using this workflow while also highlighting practical constraints associated with increasing structural complexity.

Overall, MLWDO provides a practical route toward vertically structured wireframe DNA origami while remaining compatible with existing automated routing algorithms, thereby expanding the architectural design space of DNA nanotechnology and enabling the construction of programmable layered nanostructures.

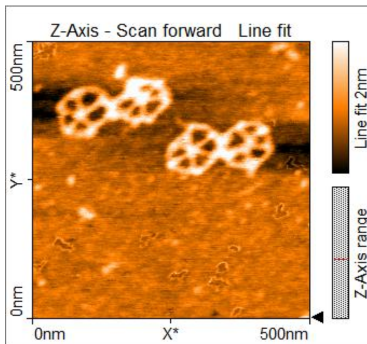

Fig 1

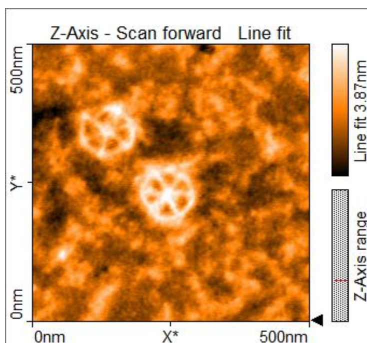

Fig 2

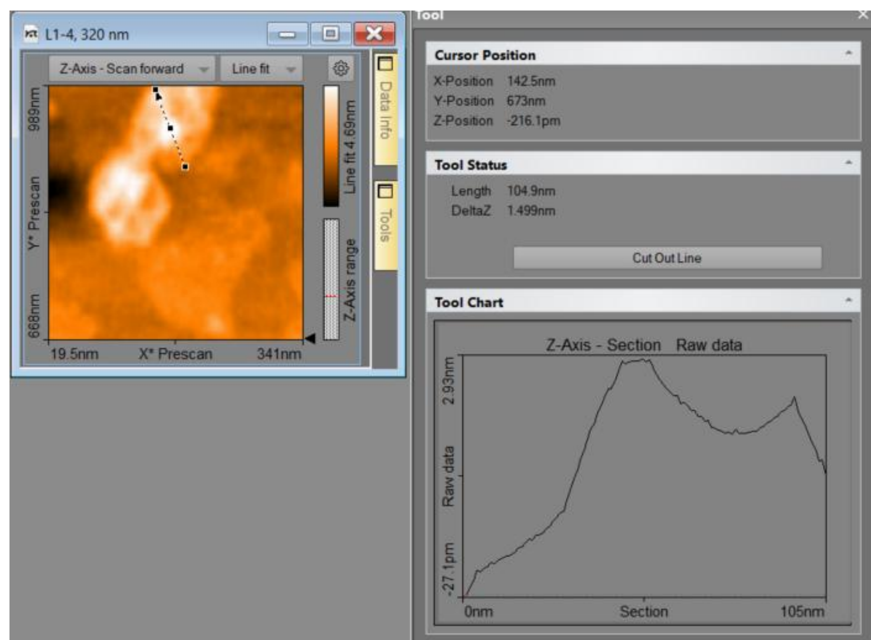

Fig 3

Fig 1: Two linked independent hexagonal wireframe structures, from the same scaffold.
Fig 2: The two overlapped and inter-layer linked hexagonal structures
Fig 3: Three partial overlapping layers vertically linked within a unified structure

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DNA Origami for multi-functional optomechanical and plasmonic assemblies

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DNA origami enables the programmable organization of objects with nanometer precision, providing a powerful route for engineering hybrid optical and plasmonic systems across multiple length scales. Integrating DNA nanostructures with microscale components offers a pathway to bridge nanoscale functional addressability with mesoscale optical architectures. However, achieving controlled bottom-up assembly of micron-sized hybrid systems remains a significant challenge. We present a bottom-up approach for assembling asymmetric (Janus-type) optomechanical probes using 24-helix bundle (24HB) DNA origami. This origami acts as a mechanical interlink between two different types of colloidal microparticles and servs as a multifunctional nano-breadboard for positioning fluorophores, quantum dots, and gold nanoparticles. Examples include 24HB DNA Origami linker connecting heterodimer microparticles (Fig. 1a-b)[1], and link of a polystyrene microsphere with a 50-nm gold nanoparticle (Fig. 1c). This configuration effectively created plasmonic gaps and enhances the localized electromagnetic field. Such three-dimensional micro-nano architecture enables accessible plasmonic hotspot and provides a programmable platform for surface-enhanced Raman spectroscopy (SERS). The modularity of the platform establishes DNA origami as a structural interface for coupling microscale manipulation with nanoscale plasmonic functionality. This approach opens new opportunities for reconfigurable nanoplasmonic assemblies, hybrid optical matter, and programmable photonic systems for sensing and spectroscopy applications.

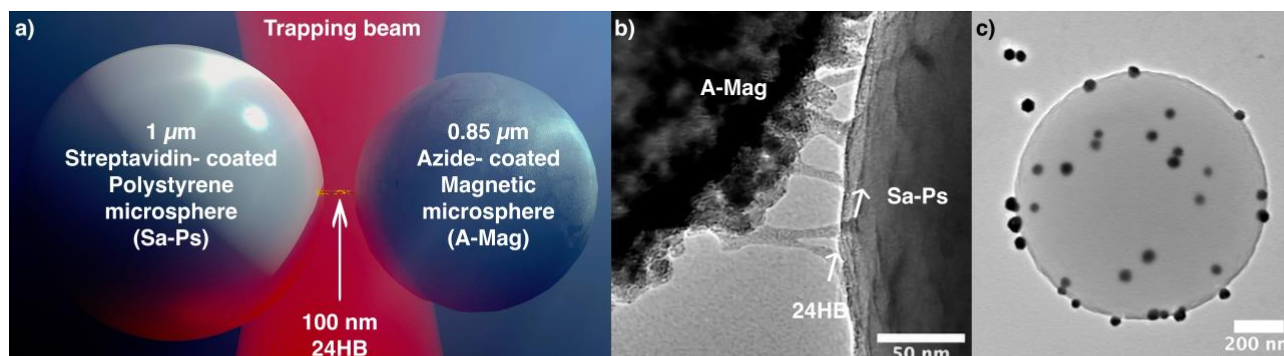

Fig. 1: Heterodimer design and characterization. a) Schematic rendering of a heterodimer interconnected by a 24HB DNA origami nanostructure functionalized with fluorophores, illustrating optical manipulation using a focused light beam, b) Representative TEM image of a formed heterodimer. c) Representative TEM image of the hybrid micro–nano configuration.

Acknowledgment: *This work has been funded by a grant from the Programme Johannes Amos Comenius under the Ministry of Education, Youth and Sports of the Czech Republic, reg. num. CZ.02.01.01/00/22_010/0013757, NanoMove and by The Czech Science Foundation project Nanophotonics with hybrid DNA origami structures (grant No. 24-11503S).*

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POSTER PRESENTATIONS

01 Improving Cellular Internalization of DNA Origami via Lipid Nanoparticle Encapsulation // Johan Farfan (Santiago de Compostella *** cancelled ***

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02 Fabrication of conductive nanowires using DNA-assisted lithography // Sima Hosseini (Leipzig)

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03 Ion-Dependent Mechanical Behavior of Ligated DNA Origami 6-Helix-Bundles // Emilia Juricke (Paderborn)

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04 Towards metasurfaces by DNA-assisted lithography // Heini Järvinen (Jyväskylä)

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05 Towards single-crystalline DNA origami lattices on silicon wafers for bottom-up nanofabrication // Thiwangi Rajapaksh (Jyväskylä)

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06 pH-sensitive DNA zippers for enhanced nanopipette biosensors // Olavi Reinsalu (Tartu)

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07 Large-scale DNA origami arrays for combating antimicrobial resistance // Yomna Gabr (Cambridge)

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08 Chirality Transfer by Helical Cyanuric Acid-Polyadenine Fibers for Optical and Catalytic Applications // Xinghua Chen (Jerusalem)

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09 Semi-Automatic Approach to Self-Assembly DNA Into Stacked Wireframe Origami Structures // Alexandru Bologa (Bucharest)

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10 Rational design of gold-palladium core-shell nanostructures for LSPR based optical biosensing // Olesia Petrova (Jena)

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11 Development of an LED-Based Multispectral Imaging System // Baihui Li (Jena)

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12 Molecular detection using LFA technology // Sanskruti Bhoir (Bologna)

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13 Benchmarking LED-based localized surface plasmon resonance spectrometry utilizing DNA-based recognition elements for detecting antimicrobial resistance genes // Florian Seier (Jena)

DNA lithography as a tool for nanoelectronics

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DNA-templated electronic nanostructures could benefit greatly from the programmability and self-assembly of DNA nanotechnology, which enables the parallel fabrication of complex nanoscale geometries. However, structures produced by direct metallization of DNA templates often suffer from limited conductivity and poor reproducibility, particularly for longer structures.

Here, we adapt DNA-assisted lithography (DALI) [1], previously developed mainly for optical nanostructures, for the fabrication of conductive nanoscale elements. Long DNA origami structures serve as templates for the oxide masks used in DALI. After assembling the origami on a sacrificial silicon substrate, we grow a SiOx layer by chemical vapor deposition. Removing the DNA leaves oxide ridges that replicate the origami geometry and act as masks for subsequent etching and metal deposition. To adapt this process for our DNA nanostructures, we adjusted the SiOx growth conditions and analyzed the resulting layer thickness and mask geometry using ellipsometry, AFM, SEM, and FIB cross sections.

Using these masks, metal nanowire geometries were fabricated and subsequently evaluated with respect to their electrical conductivity. Our results demonstrate that adapting DALI provides a promising route toward more reproducible DNA-templated nanowires. In the future, combining this strategy with other DNA-templated growth approaches and selective silicification may enable the reliable fabrication of complex multimetallic nanoscale electronic architectures.

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Ion-Dependent Mechanical Behavior of Ligated DNA Origami 6-Helix-Bundles

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The limited stability of DNA origami nanostructures in biological and application-relevant environments remains a major obstacle for their implementation. Mechanical integrity is governed by structural design parameters such as lattice type, backbone continuity, crossover position and density, which determine how DNA origami nanostructures respond to environmental conditions such as ionic composition. Previous studies on 6-helix bundle designs that differ solely in crossover spacing (21 bp vs. 42 bp) revealed that increased crossover density does not inherently enhance structural stability. Instead, a balance emerges between structural malleability and accessibility: higher crossover density reduces accessibility and thus increases resistance to nuclease degradation, yet may compromise mechanical adaptability under Mg^{2+}-free conditions.[1]

Here, we systematically investigate the interplay between crossover density, backbone ligation and divalent cation composition. The two 6-helix bundle designs (Figure 1) were enzymatically ligated to introduce phosphodiester bonds at staple nick sites, thereby increasing backbone continuity and reducing local flexibility. Mechanical properties were quantified using statistical polymer analysis to extract persistence lengths as a measure of bending stiffness (Figure 2). To disentangle ion-specific effects, the structures were analyzed in two buffer conditions: Mg^{2+}- and Sr^{2+}-based buffers.

Preliminary results indicate a pronounced ion-dependent modulation of mechanical behavior. In Mg^{2+}-containing buffers, the observed trends deviate from intuitive expectations, suggesting a complex and potentially destabilizing influence of Mg^{2+} on ligated DNA origami nanostructures. In contrast, Sr^{2+}-containing conditions show a tendency toward increased persistence lengths for ligated structures in both crossover designs, corresponding to enhanced bending stiffness and reduced conformational fluctuations. These findings suggest that the mechanical behavior of both 6-helix bundles does not arise solely from structural connectivity, but from a sensitive interplay between crossover architecture, backbone ligation, and divalent cation identity. Furthermore, Mg^{2+}, commonly used as a standard stabilizing ion, may induce unexpected mechanical responses, underscoring the importance of carefully considering ion-specific effects when engineering DNA origami nanostructures.

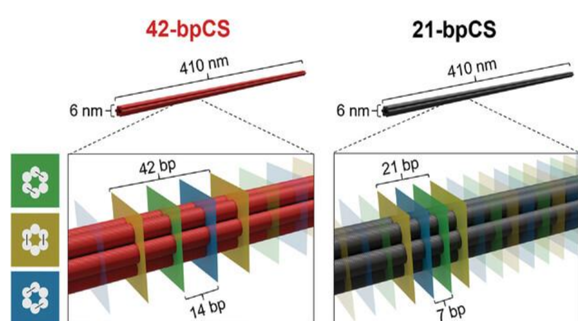

Fig. 1

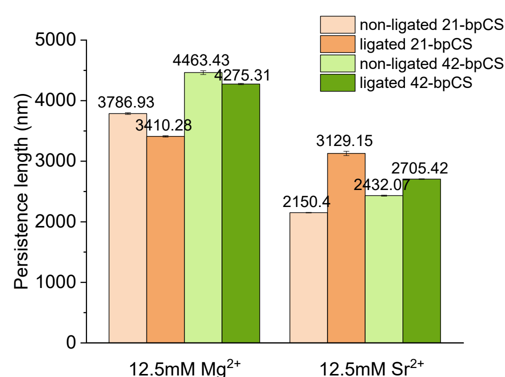

Fig. 2

Fig. 1: 6-helix bundle designs with 21-bp and 42-bp crossover spacing. Adapted from Ref. [1]
Fig. 2: Persistence lengths of ligated and non-ligated structures in Mg^{2+}- and Sr^{2+}-buffers.

[1] Xin et al. (2022). Small, 18, 2107393.

Towards metasurfaces by DNA-assisted lithography

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In the past decade, DNA origami has become one of the most used building blocks in self-assembled materials at the nanoscale [1]. Using DNA origami as tiles, large 2D lattices have been assembled with different techniques [2]. In our recent work, we have demonstrated that within certain ionic conditions the blunt-ended Seeman Tile [3] origami forms ordered 2D lattices on top of silicon [4] as shown in Figure 1b. These lattices can be further utilized in lithography processes, i.e., DNA assisted lithography (DALI) [5] (steps 1-8 shown in Figure 1). Our final goal is to fabricate a multilayered metamaterial surface with a negative refractive index within the visible range [6] to enable novel applications such as perfect lensing, optical filters, optical cloaking and more in a cost-effective manner.

For the fishnet DNA origami lattices, we have already demonstrated the DALI process midway, *i.e.,* growing silicon dioxide using the DNA lattice as a mask for the following etching step. Although further improvement of the uniformity and thickness of the oxide is still needed. Unlike in the original DALI, we now require a high precision etch process with high Si/SiO_2 selectivity and anisotropic etch profile (no undercut) to avoid the collapse of the mask. Etching has already been tested in cryogenic temperatures with SF_6 and O_2 precursors but higher etching contrast between Si and SiO_2 while keeping the profile is still needed. Currently, we are optimizing an HBr etching process in higher temperatures. Finally, we will use the etched pattern as an evaporation mask for the metallic-dielectric multilayered nanostructures.

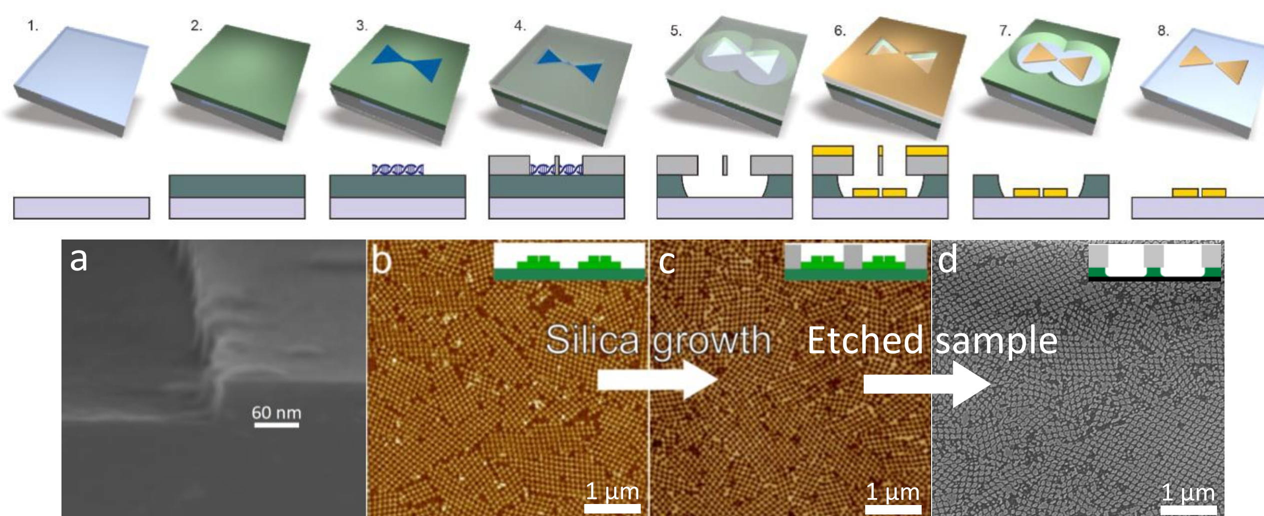

Fig. 1: DNA assisted lithography steps [5]: 1. Substrate, 2. Si growth by Chemical Vapor Deposition (CVD), 3. Origami deposition, 4. SiO_2 growth by special CVD, 5. Isotropic Si etching by Reactive Ion Etching (RIE), 6. Au deposition by evaporation, 7. Lift-off by HF:HCl wet etching, 8. Removing of Silicon by RIE. a) SEM image of e-beam lithography sample. b) AFM image of Seeman Tile fishnet-type lattice deposited on a silicon substrate. c) a Similar DNA lattice after SiO_2 growth. d) SEM image of an etched DNA lattice.

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Towards single-crystalline DNA origami lattices on silicon wafers for bottom-up nanofabrication

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DNA has emerged as a highly promising material for the fabrication of hierarchical nanostructures, due to its robust self-assembly capabilities and versatile functionalization strategies [1]. These nanostructures offer solutions to challenging fabrication processes, such as metasurfaces with unique optical properties [2], through methods like DNA-assisted lithography (DALI) [3]. DALI method combines programmable DNA origami with conventional lithographic processes to produce fully metallized metasurfaces.

Cross-shaped DNA origami (TX-tile) can be used as building blocks, i.e., tiles to form fishnet-type lattices on substrates such as mica [4]. Since further processing on mica is not possible, we have investigated similar processes on more industrial-friendly surfaces like silicon, which would allow an enormous variety of further microfabrication processes including DALI. Earlier, we developed a large-scale fabrication methodology to produce a closely spaced two-dimensional fishnet-type lattices on a silicon substrate [5]. The lattice has high surface coverage and can be extended to the wafer scale, with an average domain size of about a micrometer. By combining these lattices with DALI it is possible to obtain metasurfaces through subsequent more standard microfabrication steps. It is essential to grow the domain size toward a fully single-crystalline large lattice to further advance the optical response obtained from the corresponding metallized metasurface.

Therefore, the assembly of the polycrystalline lattice on silicon has been further optimized to increase the average domain size by changing variety of ionic environments, temperatures and origami-origami bonding strengths tuned by number of blunt-end (BE) interactions (Fig. 1a). Figure 1b shows Atomic Force Microscope (AFM) images of formed lattices and their Fast Fourier Transform (FFT) as insets. So far, we have succeeded in enhancing lattice formation, doubling the average domain diameter to ~2 µm and even achieving single crystalline lattices up to 5.6 µm^2 consisting of 670 connected DNA origami structures.

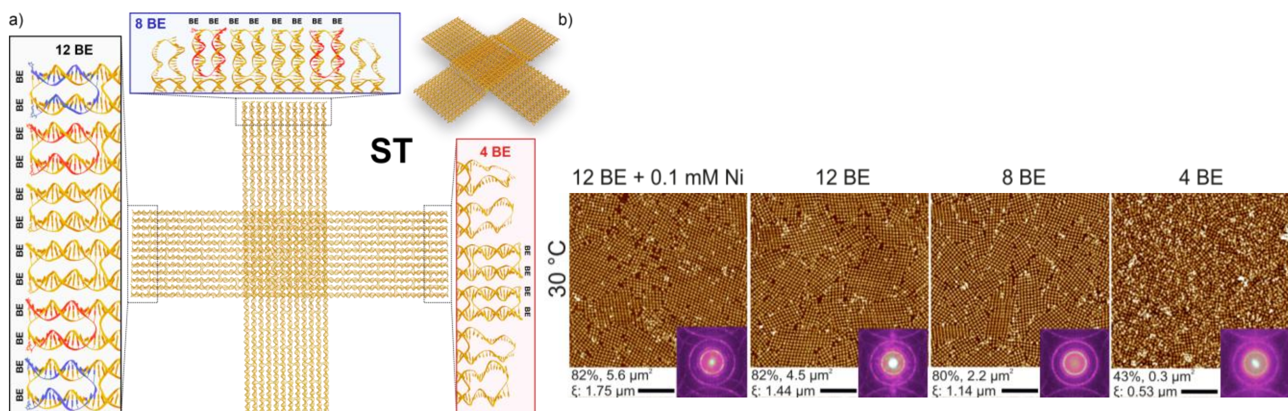

Fig. 1: a) 3D-view of Seeman tile design showing different blunt end formations [6]. b) AFM images of lattices on silicon with FFT as insets. The numbers next to the FFTs are: fraction of good lattice, largest domain and correlation length [6].

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pH-sensitive DNA zippers for enhanced nanopipette biosensors

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Nanopipette as an electrochemical biosensor is an emerging class of low-cost, rapid sensing devices that measure changes to the surface charge of its internal walls. The surface charge creates an electrical double layer (EDL) overlap at the tip, resulting in a non-ohmic electrical response known as ion current rectification (ICR). Dynamic DNA nanostructures (DONs) can be used as triggerable switches in novel chemical and biotechnological applications, including electrochemical sensing. We have designed a so-called zipper DON [1] that can adopt either a closed or open conformation, which is dependent on the (de)formation of pH-sensitive DNA triplexes. This property makes the zippers excellent sensor components for pH-dependent sensing methodologies. Here, with the zippers bound to the inner wall of nanopipette, the electrochemical device allows for a highly sensitive and tunable pH-relevant biosensor as the DON modulates the ICR based on its pH-dependent conformation.[2]

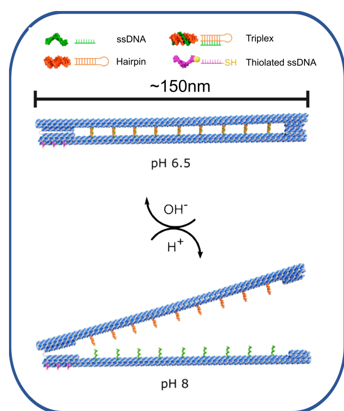

Fig. 1

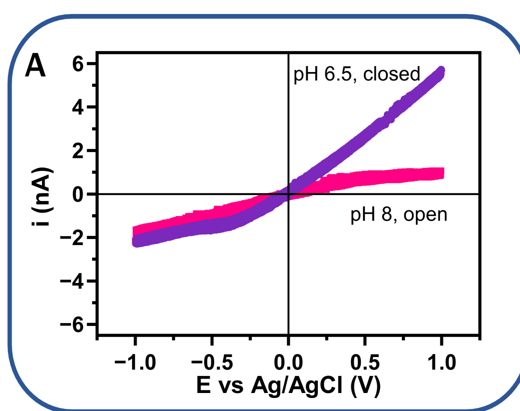

Fig. 2

Fig. 1: pH-sensitive dynamic DNA zipper nanostructure
Fig. 2: Conformation of the DNA zipper changes the ion current rectification and the polarity of the electric double layer.

[1] Williamson et al. (2021) Langmuir 37 (25), 7801–7809
[2] R. Davis et al, in preparation, 2026

Large-scale DNA origami arrays for combating antimicrobial resistance

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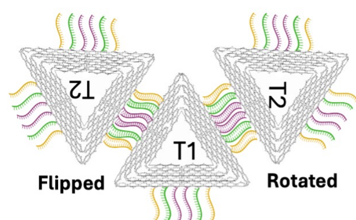
Antimicrobial resistance (AMR) has largely grown as a major challenge to the efficient treatment of infectious diseases that are associated with serious implications for human health worldwide (1). Gram-negative bacteria exhibit a high level of resistance largely due to their outer membrane barrier (2). Indeed, multi-drug resistant (MDR) Gram-negative bacteria are responsible for life-threatening infections, contributing significantly to the worldwide challenge of AMR (3).

DNA origami nanotechnology involves the folding of a long-stranded scaffold strand into a predetermined shape by hundreds of short oligonucleotides called staple strands. DNA nanotechnology has reached the degree of sophistication to construct larger, higher-order DNA origami structures with complex conformations. The hierarchical self-assembly of DNA origami building blocks could produce ordered arrays capable of manipulating lipid membranes on a greater scale bioinspired by natural membrane-sculpting proteins (4).

We present a novel endeavour for programming DNA origami self-assembly into high order, stable arrays based on sticky-end hybridisation. A two-tile design with mirrored modifications permits the hybridization of tiles whether in flipped or rotated orientation, resulting in high order arrays. By increasing surface mobility on mica surface by the use of a monovalent salt, DNA origami triangles assemble into high-order arrays with desired specificity.

Mimicking neutrophil extracellular traps (NETs), DNA origami arrays can form a sticky web on bacterial membranes entrapping and immobilising the bacteria, altering their morphology and disrupting structural integrity. Moreover, loading such arrays with antimicrobials would target bacterial drug delivery and enhance antimicrobial permeability, a double hit strategy to overcome antimicrobial resistance.



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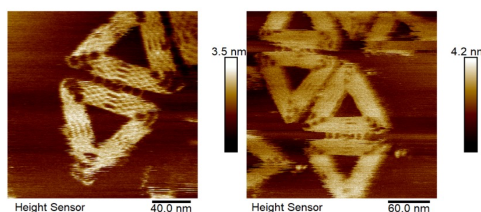

Fig. 2

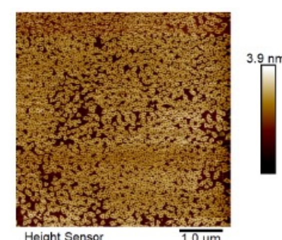

Fig. 3

Fig. 1: Schematic illustration of orientation-flexible hybridization of two triangular tiles with mirror-image sticky-ends modifications.
Fig. 2: AFM image of sticky-ends hybridisation.
Fig. 3: AFM image of large-scale DNA origami array.

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Chirality Transfer by Helical Cyanuric Acid-Polyadenine Fibers for Optical and Catalytic Applications

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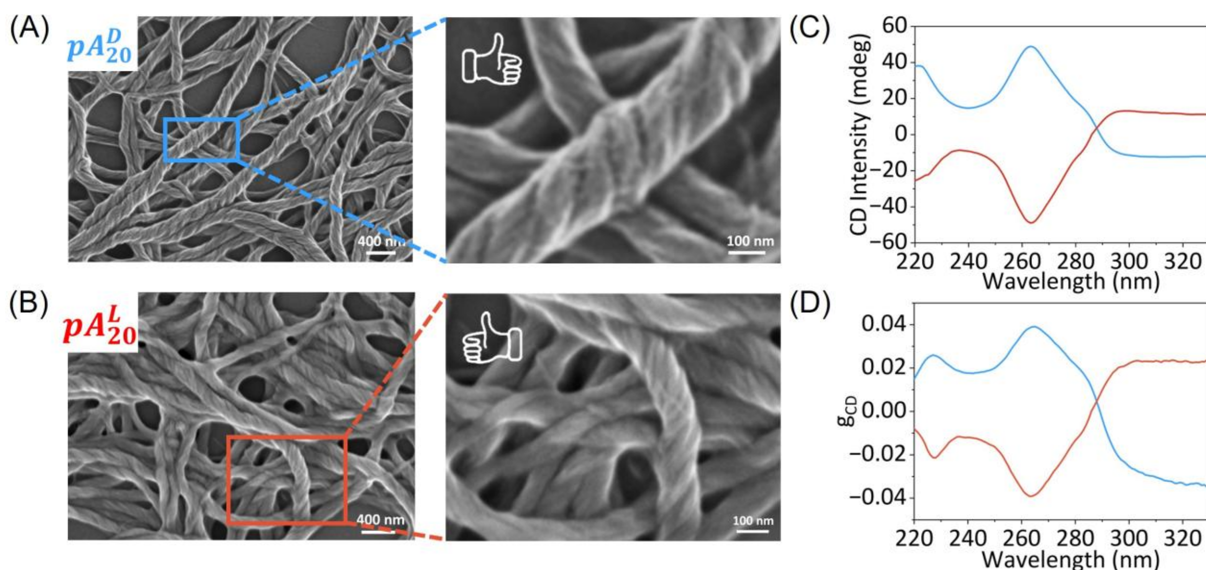
D- or L-polyadenine, pA, strand self-assembly, in the presence of cyanuric acid (CA), into left-handed or right-handed helical fibers consisting of CA/pA triplex subunits. Formation of the chiral fiber is supported by scanning electron microscopy (SEM) and circular dichroism (CD) measurement and molecular dynamic (MD) simulations. The left-/right-handed helical CA/pA fibers reveal optical or catalytic chirality transfer-functions. Integration of achiral Hoechst 33258 ligand into left-/right-handed helical fibers results in optical chirality transfer to the intercalated ligand reflected by opposite CD and opposite circularly polarized luminescence (CPL) properties. Catalytic chirality transfer by left-/right-handed helical CA/pA fiber is demonstrated by tethering catalytic units to the chiral fibers, turning the supramolecular assemblies into chiral nanozymes. Hemin/G-quadruplex tethers linked to the left- or right-handed helical fibers reveal catalytic chirality transfer functions towards chiroselective catalyzed oxidation of D-/L-DOPA by H_2O_2 to form dopachrome. While the hemin/G-quadruplex-tethered left-handed CA/pA fiber reveal a ca. 2-fold enhanced oxidation of D-DOPA, as compared to L-DOPA, the left-handed helical hemin/G-quadruplex-tethered CA/pA fibers demonstrate a ca. 2-fold enhanced oxidation of L-DOPA, as compared to D-DOPA. In addition, catalytic chirality transfer to Cu^{2+}-bipyridine-functionalized left-/right-handed helical fibers towards chiroselective H_2O_2 oxidation of D-/L-DOPA to dopachrome is demonstrated (albeit in opposite directionality to that observed for the hemin/G-quadruplex catalyst).



(A): SEM images of left-handed helical CA/pA fibers formed through the assembly of D-pA with CA.
(B): SEM images of right-handed helical CA/pA fibers formed through the assembly of L-pA with CA.
(C): CD spectra of left-handed (blue) and right-handed (red) helical CA/pA fibers
(D): g_{CD} spectra of left-handed (blue) and right-handed (red) helical CA/pA fibers

INCDSB

Semi-automatic Approach to Self-Assembly DNA Into Stacked Wireframe Origami Structures

Authors

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National Institute for Research and Development of Biological Sciences, Bucharest, Romania

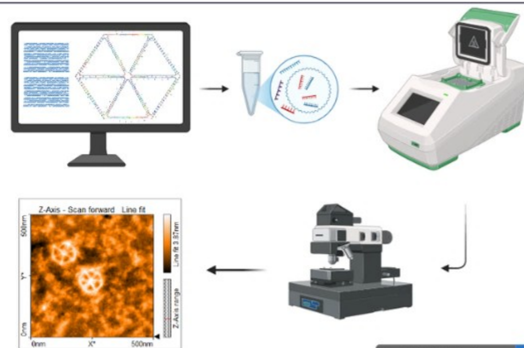
* These authors contributed equally to this work.

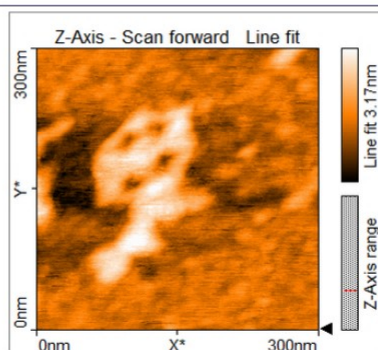
Methods

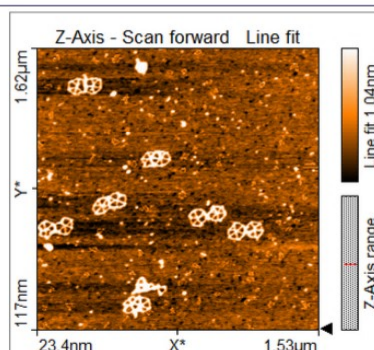
- The 7249-nucleotide M13mp18 single-stranded DNA scaffold;
- Custom DNA oligonucleotides used as staple strands;
- PERDIX [3] was employeed to design individual layers of the target architecture;
- Inhouse algorithm and manual curation to position layers by a shared coordinate system;
- Atomic force microscopy (AFM) imaging of the structures fixed on the mica surface.

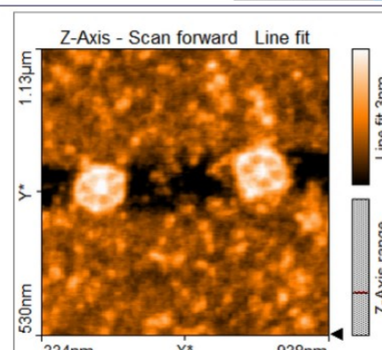
Introduction

- One of the most studied element in cells, the genetic material is also a powerful building block in the world of nanobiotechnology. Using DNA origami, a technique that involves tens/hundreds of short DNA oligonucleotides incorporated to fold a long single-stranded DNA sequence, various molecular assemblies at the nanoscale with customized shapes, can be designed [1]. The key to assemble more complex structures in an automated manner, both from the perspective of computational design and experimental feasibility, is to understand how short staples control the folding of the long scaffold [2].
- Herein, we describe a semiautomated method to construct multilayered wireframe DNA origami as vertically stacked structures through inter-staples connections.



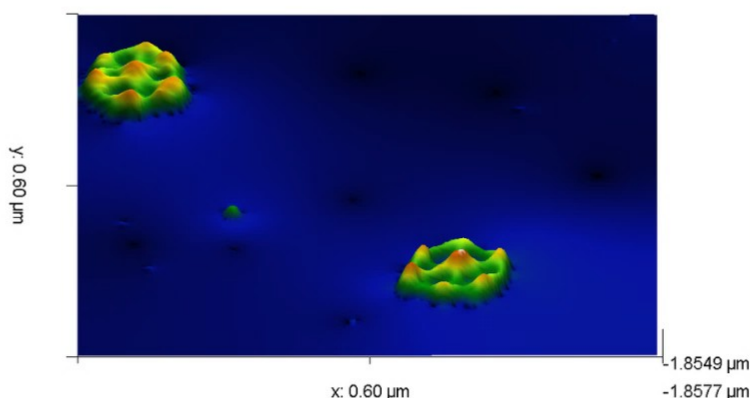






Results

- Fig. 1. First layer of the hexagonal structure consisting of the first 3418 nt out of 7249 of the scaffold.
- Fig. 2. Two linked hexagonal wireframe structures, built from the same scaffold.
- Fig. 3+4. The two independent hexagonal structures formed through the overlapping of two layers connected through inter-staple strands.
- **Workflow:** Designing the first hexagonal layer involves the partial use of the M13mp18 scaffold in combination with 81 staple sequences. The unused scaffold serves as a model sequence from which layer 2 is next to be formed, before being overlapped on layer 1. Finally, by replacing some of the staples that led to the formation of the two bonded layers with connection inter-staples, the two layers are brought together one on top of the other through an accurate positional association.



Conclusion

DNA origami proved to be a versatile platform with a high degree of customization and spatial variability. However, the size and complexity of a DNA origami structure are limited by the length of the scaffold; the most commonly used scaffold is M13mp18, extracted from bacteriophage M13. By designing multi-layer and multi-scaffold structures, the capabilities open up opportunities for a broad range of applications in chemistry, biology, physics, materials science, and computer science.

Future perspectives

Improvements of the inhouse algorithm in order to identify common points and spatially align each layer created with PERDIX. In a final step, the algorithm defines a pair of points as an inter-layer connection and generates the definitive staple sequences set for a given number of layers.

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Rational design of gold-palladium core-shell nanostructures for LSPR-based optical biosensing

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New design strategies in plasmonic nanostructures reshape optical biosensing, enabling highly sensitive, real-time, label-free detection. In this context, localized surface plasmon resonance (LSPR) is a key method for probing refractive index changes in the surrounding medium, with performance controlled by nanoparticle size, shape, and composition [1,2]. Careful tuning of these parameters allows spectral control over a broad wavelength range and precise manipulation of local electromagnetic fields essential for analyte detection. However, achieving reliable control over nanoparticle morphology in order to tailor plasmonic properties remains a disturbing challenge. Bimetallic core-shell nanostructures, consisting of gold or palladium cores coated with secondary metals such as platinum or palladium, offer a promising solution [3,4]. Their combined optical properties, along with controlled aspect ratio, surface roughness, and tip geometry, enable enhanced electromagnetic fields at nanoscale hot spots and improved spectral flexibility, thereby strengthening the LSPR response for high-performance biosensing.

In this work, we investigate controlled palladium growth on pre-synthesized gold nanorods to produce Au@Pd core-shell nanoparticles with varied morphologies. By tuning parameters such as palladium precursor concentration, temperature, and pH, different structures can be obtained, including rod- or bar-like nanoparticles with uniform shells or crystallite-decorated surfaces. The spectral variations in the UV-Vis extinction data, including red or blue shifts and changes in the longitudinal LSPR band shape relative to the gold nanorod reference, reflect the morphological diversity observed in SEM images (Fig. 1) and indicate that the optical response of the bimetallic nanostructures is strongly influenced by the Pd shell properties, such as thickness, continuity, shape, and surface structure, along with the contribution of the gold core. The synthesized nanoparticles exhibit wide optical tunability, underscoring their potential for designing advanced LSPR-based biosensors. Future work will focus on sensing studies and integrating these nanoparticles into LSPR platforms to fully explore their plasmonic and sensing performance.

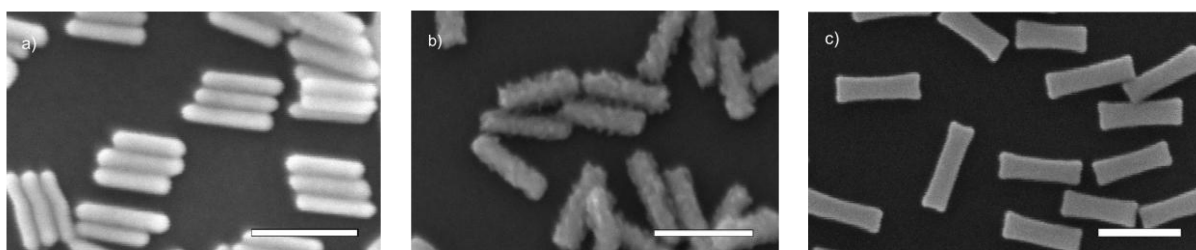

Fig. 1: Scanning electron microscopy (SEM) images of gold nanorods (a) and Au@Pd core-shell nano-particles (b, c). Scale bars are 100 nm

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Development of an LED-Based Multispectral Imaging System

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Bioanalytical sensing based on the principle of localized surface plasmon resonance (LSPR) is developing rapidly, and new sensors with novel plasmon sensors and innovative concepts of signal development and readout principles have been discovered one after another [1]. The resonance frequency of LSPR sensing depends on several intrinsic factors. One is the material of the nanostructure. The geometry of the nanostructure is another important factor in its sensing properties, as is its size. [2]. Combined with imaging spectrometer equipment, multiplexing methods have been proven to be very effective in studying the spectral behavior of plasmonic nanoparticles when the refractive index changes [3]. Especially, plasmonic microarrays, tens of nanoparticle spots, can be used for the detection of around 100 biomarkers in one assay. Although LSPR measurements are commonly performed in transmission mode, scattering-based detection provides a viable alternative approach. To enhance the compactness and sensitivity of LSPR detection systems, a scattering-based experimental setup is developed and systematically compared with conventional transmission-based methods in terms of sensitivity, signal stability, and suitability for dynamic measurements.

This research focuses on designing and developing a new multi-spectral imaging sensor for LSPR sensing. Building on the existing "6-spectral imaging sensor", the project aims to achieve high integration, miniaturization, and portability of sensor systems, enhancing its practicality for experimental applications [4]. The proposed design not only enhances the practicality of the system for experimental applications but also reduces overall device costs. Even point-of-care applications in bioanalytic. It provides an interesting alternative for the development of future on-site diagnostics.

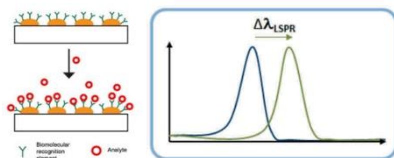

Fig. 1

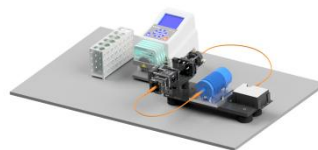

Fig. 2

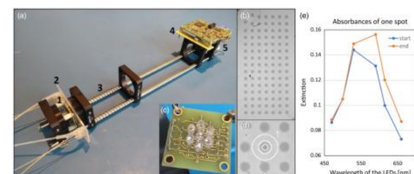

Fig. 3

Figure 1: Analytes binding to biomolecular recognition element on top of AuNP inducing apeak shift of LSPR.

Figure 2: Transmission-Mode Setup for LSPR.

Figure 3: a) Measurement setup: 1-camera, 2-microfluidic chip, 3-springs, 4-electronic LED control, 5-LEDs with diffuser plate. b) Microarray sensor chip. c) Circuit board with six mounted LEDs. d) Measurement area for sample I and reference I_0 values. e) Spectral shift of one AuNP spot during sensing measurement [4].

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Molecular Detection using Lateral flow assay (LFA) technology

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Lateral flow assay (LFA) platforms provide a simple, low cost and rapid format for molecular detection, yet their conventional colorimetric readout limits sensitivity and restricts quantitative analysis (Fig. 1). In this work describes the development of LFA for the detection of rheumatoid factor (RF) in human serum, targeting the serological diagnosis of rheumatoid arthritis (RA) at the point of care. Rheumatoid arthritis is a chronic systemic autoimmune disease affecting approximately 1% of the global population, with RF- an IgM autoantibody directed against the Fc region of human IgG - representing one of the primary diagnostic biomarkers included in the 2010 ACR/EULAR classification criteria [1]. Despite its clinical importance, RF detection currently depends on laboratory-based platforms including ELISA and nephelometry, which are incompatible with resource-limited or decentralized diagnostic settings. The development of an RF-specific LFA introduces unique technical challenges beyond conventional antigen-detection formats, including competitive interference from endogenous free IgG in serum, the large pentameric structure of IgM and its implications for membrane diffusion kinetic and the risk of prozone effect at elevated R. concentrations [2].

The proposed LFA strip employs a mouse anti-RF monoclonal antibody conjugated to 30 nm AuNPs on the conjugate pad as the primary detection element, which binds IgM-RF directly via recognition of the rheumatoid factor epitope; the resulting AuNP–IgM-RF complex is subsequently captured at the test line by immobilized human IgG Fc fragment, which retains the complex through the natural affinity of IgM-RF for the IgG Fc region. To optimize antibody functionalization of the AuNPs, a binding curve was generated by incubating increasing concentrations of mouse anti-RF antibody with AuNPs to determine the loading plateau and ensure maximal nanoparticle surface coating. Conjugate robustness was assessed through a NaCl stability challenge, in which the aggregation state of antibody-functionalized AuNPs was monitored by UV-Vis absorbance shift as a function of salt concentration confirming colloidal stability and adequate surface passivation prior to strip assembly [3].

These conjugate characterization steps provide the quantitative foundation for reproducible LFA fabrication and ensure reliable recognition of the IgM-RF analyte under assay conditions. Subsequent work will address full strip fabrication and assembly, optimization of sample dilution to mitigate free IgG competition at the test line and analytical validation of sensitivity and specificity against across a clinically relevant range of RF titers in human plasma. This work establishes the core assay architecture and conjugate optimization framework for a rapid, low-cost POC diagnostic device for RA serology.

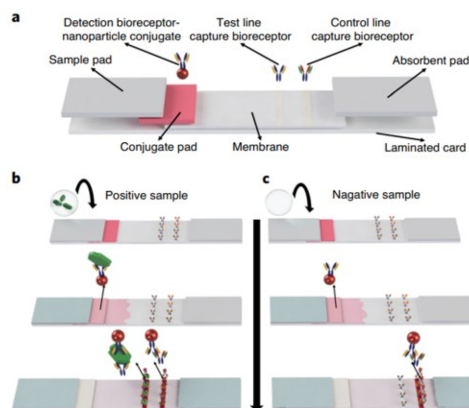

Fig. 1

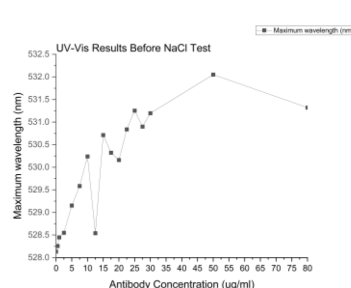

Fig. 2

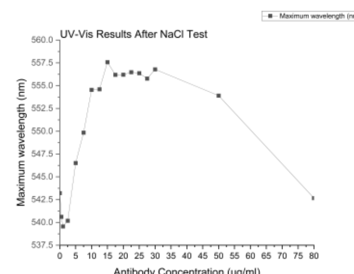

Fig. 3

Fig. 1: Schematic of the main components and operation of a typical LFA.

Fig. 2: UV-Vis Absorbance Response Curve for AuNP–Antibody Conjugation Before NaCl Test

Fig. 3: UV-Vis Absorbance Response Curve for AuNP–Antibody Conjugation After NaCl Test

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Benchmarking LED-based localized surface plasmon resonance spectrometry utilizing DNA-based recognition elements for detecting antimicrobial resistance genes

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Humanity faces an ongoing threat from pathogenic organisms, such as viruses and bacteria, which are evolving rapidly to develop resistance to standard treatments. Addressing this challenge requires diagnostic tools that are fast, sensitive, cost-effective, and easy to use [1,2]. Localized Surface Plasmon Resonance (LSPR) spectroscopy has emerged as a highly promising solution. This technique utilizes noble metal nanoparticles that, when exposed to incident light, induce collective oscillations of free electrons. This phenomenon causes the nanoparticles to absorb light at a specific frequency - a wavelength that is highly sensitive to the local refractive index of the nanoparticle's immediate environment. Because unmodified nanoparticles lack inherent biological specificity, they must be functionalized with recognition elements. By coating these nanoparticles with specific single-stranded DNA sequences, we can program the sensor to selectively hybridize with target pathogens [2, 3]. To enable the screening of multiple pathogens simultaneously, we utilize a microarray format [4]. While traditional LSPR requires bulky, expensive spectrometers, this approach is often impractical for portable, point-of-care environments. To address this, an imaging-based detection system has been developed. By using a light source composed of six discrete colored LEDs and a high-resolution camera, we can simulate spectral analysis [5, 6].
By calculating the "center of mass" of the absorption peak - based on the intensity data captured across the different LED wavelengths - we can observe binding events as they occur. This allows for the real-time confirmation of target pathogen DNA, effectively transforming a complex laboratory measurement into a streamlined, portable, and accessible diagnostic process.

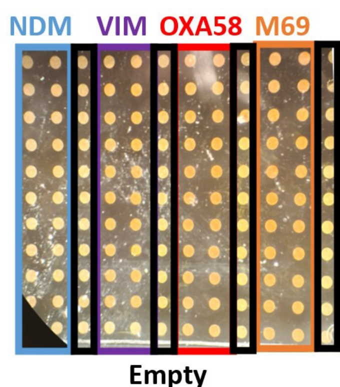

Figure 1: Plasmonic microarray with 80 nm Au-spheres and NDM, VIM OXA58, and M69 captures with target (left to right).

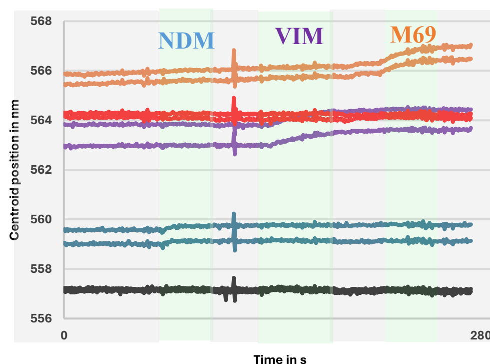

Figure 2: LSPR-Sensorgram showing the specific binding of NDM (blue), VIM (purple), and M69 (orange) targets to their respective captures, while the negative control DNA and the empty spots remain stable.

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