Development of DNA-based conducting nanowires

Résumé en français

En raison des dimensions nanométriques de la double hélice d'ADN (diamètre de 2 nm), cette molécule d'origine naturelle apparait comme un chassis prometteur pour la métallisation et la production à bas coûts de nanofils métalliques. Depuis les premières preuves de concept publiées il y a une vingtaine d'année, de nombreux efforts ont été produits pour obtenir des nanofils de plus en plus fin à partir d'une matrice d'ADN, tout en montrant des propriétés de conductivité satisfaisantes. En collaboration avec un autre laboratoire grenoblois (LMGP, INP-Grenoble), nous souhaitons développer une voie alternative pour la production de nanofils d'ADN métallisés par Atmospheric Pressure Spatial Atomic Layer Deposition (AP-SALD). Plusieurs métaux seront utilisés, et en particulier l'or et le cuivre. Ce nanomatériau sera ensuite fonctionnalisé, et conjugué à d'autres biomolécules afin de tirer profit de l'immense surface développée présentée par ces nanostructures. Ce projet de doctorat a donc pour objectif de synthétiser, développer et caractériser un nouveau matériau dont les propriétés intrinsèques seront modulables grâce à l'ADN. Un des objectifs principaux sera alors le design de surfaces greffées par des enzymes, dont les applications seraient de première importance, notamment pour la production de biopiles de nouvelle génération.

Summary

Due to the nanometric diameter of a DNA helix (2 nm), this biological molecule appears as a promising scaffold for metallization and low-cost production of metallic nanowires. Since the very first proof-of-concept published 20 years ago, many efforts have been made to explore new routes enabling thinner DNA-based nanowires, with higher conductivity. In collaboration with another laboratory (LMGP, INP-Grenoble), we wish to design an alternative approach based on Atmospheric Pressure Spatial Atomic Layer Deposition (AP-SALD) for the metallization of DNA. Several metals will be used, with a specific emphasis on Cu and Au. Then, such nanomaterial will be functionalized, and conjugated with biomolecules to take benefit of the huge developed area of such active bio-hybrid architectures. This PhD research project thus aims at synthesizing and characterizing new materials made of tuneable and controllable conducting nanowires. A major goal will be the design of enzymatically-active surfaces, whose applications would be a great interest for the production of more powerful biofuels for instance.

Detailed subject

DNA is a biological polymer whose length, self-assembling and structure can be easily designed and tuned by chemists. It is also considered as an exciting material by nanotechnologists as the diameter of a double-stranded DNA is 2 nm, and can thus be used to create 1D, 2D and 3D structures. This molecular object is used, for 20 years now, as a tuneable scaffold to create metallic nanowires in "bottom-up" approaches. Most results published so far in this field involved metallic ion reduction in solution, and had to face with a compromise between the nanowire diameter (expected to be small) and the conductivity (expected to be high). In this context, we wish to explore how alternative approaches, like Atmospheric Pressure Spatial Atomic Layer Deposition (AP-SALD), might be used for DNA-templated vapor deposition of metals. Preliminary results obtained in our hands confirmed the suitability of DNA to be used as a scaffold for Copper nanowires, although the dimensions (> 200 nm in diameter) were much larger than the initial DNA scaffold. AP-SALD should give access to thinner metallic nanowires, either made of Cu (for conductivity measurements) or Au (for biomolecule grafting). The SyMMES lab has more than 20-years of experience in the production of Au-covered biochips functionalized with DNA, peptides, proteins, sugars... Based on this expertise, we wish to create high-density networks of Au nanowires functionalized with proteins. Among the most relevant biomolecules to be grafted, enzymes and more specifically redox enzymes will be immobilized to take benefit of the material conductivity, either to catalyze reaction, or measure the enzymatic activity and also electron collection. It will be very exciting to extend such new bio-hybrid nanomaterial to the production of enzymatically active anodes and cathodes to propose highly efficient biofuels.

References

1. Chen, Z.; Liu, C.; Cao, F.; Ren, J.; Qu, X., DNA metallization: principles, methods, structures, and applications. *Chem Soc Rev* **2018,** *47* (11), 4017-4072.
2. Brun, C.; Diagne, C.T.; Elchinger, P.H.; Torrengo, S.; Thuaire A.; Gasparutto, D.; Tiron, R.; Baillin X., DNA for Nanopackaging : A promising bottom-up approach. *IEEE Nanotechnology Magazine* **2017**, 12-19. (DOI 10.1109/MNANO.2016.2633679)
3. Brun, C.; Elchinger, P. H.; Nonglaton, G.; Tidiane-Diagne, C.; Tiron, R.; Thuaire, A.; Gasparutto, D.; Baillin, X., Metallic Conductive Nanowires Elaborated by PVD Metal Deposition on Suspended DNA Bundles. *Small* **2017,** *13* (33).
4. Munoz-Rojas, D.; MacManus-Driscoll, J., Spatial atmospheric atomic layer deposition: a new laboratory and industrial tool for low-cost photovoltaics. *Mater Horizons* **2014,** *1* (3), 314-320.
5. Cusma, A.; Curulli, A.; Zane, D.; Kaciulis, S.; Padeletti, G., Feasibility of enzyme biosensors based on gold nanowires. *Mat Sci Eng C-Bio S* **2007,** *27* (5-8), 1158-1161.
6. Bagal-Kestwal, D. R.; Pan, M. H.; Chiang, B. H., Electrically nanowired-enzymes for probe modification and sensor fabrication. *Biosens Bioelectron* **2018,** *121*, 223-235.

Context

This project will be shared by two laboratories of the Grenoble Scientific Polygone campus, the Laboratory in Materials Science and Physical Engineering (LMGP, http://www.lmgp.grenoble-inp.fr/welcome-to-lmgp/laboratory-in-materials-science-and-physcical-engineering-527707.kjsp) and the Laboratory for Systems made of Molecules and nanoMaterial for Energy and Health (SyMMES, http://inac.cea.fr/en/Phocea/Vie_des_labos/Ast/ast_service.php?id_unit=1148). This multi-disciplinary internship will enable the student to work on biomolecule engineering, surface chemistry, atomic layer deposition and use the dedicated characterizing techniques available in both laboratories.

Contacts

Dr Didier Gasparutto; https://www.researchgate.net/profile/Didier_Gasparutto; didier.gasparutto@cea.fr
Dr David Munos-Rojas; http://www.lmgp.grenoble-inp.fr/annuaire-/m-munoz-rojas-david--567822.kjsp; david.munoz-rojas@grenoble-inp.fr