ACES Asian Chemical Editorial Society

DOI: 10.1002/asia.201900722

CHEMISTRY AN ASIAN JOURNAL Editorial

Smart Chemistry, Smart Motors

Yimeng Chen, Borui Xu, and Yongfeng Mei*[a]

Micro- and nanomotors that use various kinds of energy from their surrounding environment and convert it to kinetic motion are a prominent part of emerging nanotechnology, which could improve all aspects of human life.[1] These tiny devices capable of artificial autonomous motion can be chemically and biologically functionalized and designed to perform complex and specific tasks, such as drug delivery, cargo transport, environmental monitoring and remediation.[2] From the accessible energy supply for conversion to the application stage in reality, diverse aspects of micro/nanomotors need to be considered and interweaved around chemistry, which plays an important role in the majority of micro- and nanomotors within this field.[3]

Nowadays, numerous smart devices with intelligent functions were realized spanning from the macroscale[4] to the microworld.[5] With the development of nanotechnology, "smart" motors were also developed that hold great potential for unprecedented applications.[6] Consequently, current micro- and nanomotors will enter the next stage of evolution in which these devices are integrated with smart systems, holding considerable promise for executing a series of more complicated and challenging tasks from biological and medical technology to bioinspired robots. To this end, precisely designed and accurately regulated micro- and nanomotors are desired for more groundbreaking research. As a result, this special issue highlights contributions of chemists and materials scientists to make smart micro/nanomotors and looks forward to more achievable applications by smart motors.

It is of critical importance in this area of research to understand the motion behaviors of micro/nanomotors with different structures and find out where their energy input comes from.[7] In this special issue, a tutorial review from Wang et al. gives a brief introduction on colloidal motors containing the elucidation of important concepts, which can equip the beginners with a core knowledge in a friendly and convenient way. Li et al. focused on the interaction behaviors of micro/nanomotors and showcased the recent progress regarding interaction capabilities, providing inspiration for the design of nanomachines cooperating with each other for more attractive and smart applications. Moreover, Peng et al. summarized the driving mechanism of fuel-free micro/nanomotors beyond chemically-propelled counterparts and reviewed recent advances pertaining to biomedical applications. A reviews by Lu et al. concentrated on the development of micro/nanomotors driven by ultrasound power sources.

With advanced microfabrication methods, micro/nanomotors were designed and processed into distinct geometries to transform energy for their autonomous movement with the goal of functional micro/nanomachines including tubes, Janus spheres, rods, helices and other novel structural shapes.[8] In this special issue, micro/nanomotors with diverse morphologies, impelled using the pioneered bubble propulsion mechanism,[9] are presented in several articles. Ma et al. reported on Pt-based catalytic helix micro/nanomotors capable of being driven by the decomposition of hydrogen peroxide, of which the motion behaviors were closely related with helical turn numbers. The influence of the micro/nanomotor's size on the motion was investigated by Wu et al. with enzyme-powered microshells; they comply with a size-dependent locomotion mechanism. Furthermore, an updated strategy for fabricating micro/nanomotors with 3D lithography was proposed by Mei et al. They exemplified an advanced rocket-shape micro/nanomotor with enhanced moving speed compared with that of normal tubular micro/nanomotors. Additionally, in the contribution from Wu et al., a bubble-dragged catalytic polymer tubular microrocket was devised, for which the forward motion is dragged by fast ejection of a shock wave of oxygen gas.

To achieve more promising practical applications, diverse approaches were developed to regulate the movement of micro/nanomotors, including their velocity, direction and other motion states.[10] In this special issue, Dong et al. realized photocatalytically bubble-driven tubular micromotors with both a strong propulsion ability and efficient direction control by using magnetic field. He et al. achieved a continuously variable-speed regulation of bubble-propelled Janus micro/nanomotors grafted with salt-responsive brushes, which autonomously respond to their surrounding chemical environment with accuracy and predictability. Beyond the control of single micro/nanomotors, a dynamic assembly of a group of micro/nanomotors was proposed by Li et al. and Xu et al.. The former designed a simple and highly precise method to form desired shapes by utilizing the light induced self-assembly of semiconductor nanomotors, creating new possibilities for functional surface science, while the latter report an extensive study on the microsphere assembly behaviors under an ultrasound field, which could be applied as an approach for the construction of complex structures.

[a] Y. Chen, B. Xu, Prof. Y. Mei
Department of Materials Science
Fudan University
220 Handan Road, Shanghai 200433 (China)
E-mail: yfm@fudan.edu.cn

This manuscript is part of a special issue on Smart Chemistry, Smart Motors. Click here to see the Table of Contents of the special issue.

These developed smart motors may hold extraordinary potential for real applications in various aspects.[11] Tu et al. covered the current advances of micro/nanomotors in active drug delivery and summarized a series of applications to classify them into the delivery of small molecules, nucleic acids and macromolecular proteins for new breakthroughs in this field. Meanwhile, Liu et al. discussed the recent progress in environmental and biomedical applications employing metal-based transient micromotors inspired by transient devices. Such transient micro/nanomotors can autonomously disappear after accomplishing their assigned tasks, which provides prospects for unique performances and fascinating functionalities. In this special issue, outstanding research work on concrete practical applications of micro/nanomotors were introduced. For instance, a tubular micro/nanomotor was prepared by Mei et al. by employing strain engineering to roll up monolayer graphene with a nanomembrane. Such a motor exhibits an enhanced performance with regard to speed and antibacterial property as a bacteria killer for in vivo applications. Guan et al. developed a kind of tubular polyethyleneimine-functionalized micro/nanomotor as a versatile and reversible tool to extract nucleic acids in microsystems. These modified micro/nanomotors can selectively capture nucleic acids from acidic solutions and release them into alkaline solutions with high efficiency.

Furthermore, a number of neotype micro/nanomotors towards smart functions were proposed in this special issue. Pumera et al. developed a UV-light-driven TiO_2/Pt Janus micromotor as one kind of smart microdevice, which is competent in returning back to its initial position following the original path without guidance once the external energy input is interrupted. These synthetic micro/nanomotors are generally engineered to show "smart" behaviors inspired by living systems possessing the ability to find their way home even in complicated environments.[12] Another kind of smart device was demonstrated by Cheng et al. who present a self-propelled motor to collect oil spills on the water surface, offering potential applications for water remediation. In addition, contributions from Solovev et al., who reported on a portable oxygen generator via tunable catalytic Ti/Cr/Pt microtubes, and Xiao et al., who designed an innovative mini-generator converting chemical energy into electrical energy based on vertical motion of a self-propelled motor, promote the development of self-powered devices. More smart functions can be achieved with stimuli-responsive materials as introduced by Du et al.. They highlighted a class of polymers which could respond to various stimuli and serve as bioinspired actuators. Future research on motors combined with these materials in smart chemical manners would open up a new era of micro/nanomotors with advanced functions.

The past few decades have witnessed rapid development of distinct micro/nanomotors, and the contributions in this special issue represent recent advances in smart artificial motors for miscellaneous applications. Based on these achievements, we believe that more sophisticated smart motors will be created and more intelligent functionalities will be realized utilizing smart chemistry strategies toward further improving human life and society in the future.

Yongfeng Mei, Guest Editor

[1] M. Guix, C. C. Mayorga-Martinez, and A. Merkoci, *Chem. Rev.* **2014**, 114, 6285 – 6322.
[2] W. Wang, W. Duan, S. Ahmed, T. E. Mallouk, A. Sen, *Nano Today* **2013**, 8, 531.
[3] J. G. S. Moo, C. C. Mayorga-Martinez, H. Wang, B. Khezri, W. Z. Teo and M. Pumera, *Adv. Funct. Mater.* **2017**, 27, 1604759.
[4] T. J. Wallin, J. Pikul and R. F. Shepherd, *Nat. Rev. Mater.* **2018**, 3, 84 – 100.
[5] L. Hines, K. Petersen, G. Z. Lum, and M. Sitti, *Adv. Mater.* **2017**, 29, 1603483.
[6] Y. F. Mei, A. A. Solovev, S. Sanchez, O. G. Schmidt, *Chem. Soc. Rev.* **2011**, 40, 2109 – 2119.
[7] T. Xu, W. Gao, L. P. Xu, X. Zhang, S. Wang, *Adv. Mater.* **2017**, 29, 1603250.
[8] a) B. R. Xu, B. R. Zhang, L. Wang, G. S. Huang, Y. F. Mei, *Adv. Funct. Mater.* **2018**, 28, 1705872; b) W. Gao, A. Pei, J. Wang, *ACS Nano* **2012**, 6, 8432; c) S. Sundararajan, P. E. Lammert, A. W. Zudans, V. H. Crespi, A. Sen, *Nano Lett.* **2008**, 8, 1271; d) A. Ghosh, P. Fischer, *Nano Lett.* **2009**, 9, 2243; e) B. J. Williams, S. V. Anand, J. Rajagopalan, M. T. A. Saif, *Nat. Commun.* **2014**, 5, 3081.
[9] Y. F. Mei, G. S. Huang, A. A. Solovev, E. Bermudez Urena, I. Monch, F. Ding, T. Reindl, R. K. Y. Fu, P. K. Chu, O. G. Schmidt, *Adv. Mater.* **2008**, 20, 4085 – 4090.
[10] D. Kagan, R. Laocharoensuk, M. Zimmerman, C. Clawson, S. Balasubramanian, D. Kang, D. Bishop, S. Sattayasamitsathit, L. Zhang, J. Wang, *Small* **2010**, 6, 2741 – 2747.
[11] J. X. Li, B. E. Fernandez de Avila, W. Gao, L. F. Zhang, J. Wang, *Sci. Robot.* **2017**, 2, eaam6431.
[12] J. Plutnar and M. Pumera, *Angew. Chem. Int. Ed.* **2019**, 58, 2190 – 2196.