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Nanobiodevices and AI for Society 5.0: Super Smart Society

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During the past decade, nanobiodevice has progressively begun to focus on the establishment of main four fields of biomedical applications of nanotechnology, including 1) diagnostic devices, 2) molecular imaging, 3) regenerative medicine, and 4) drug delivery systems. The research efforts in my laboratory have been focused on the development of nanodevices, nanomaterials, and nanotechnologies intended for biomedical applications, including genome and proteome analysis, analysis of biomolecules and cells, diagnosis of diseases, intra vital imaging, stem cell therapy, tissue engineering, and gene delivery systems [1-25]. Since nanobiodevices have the tremendous advantages, they are applicable to fast analysis of biomolecules developed by appropriate small space, which have short diffusion distance biomolecules, with extremely small diffusion constants. Highly sensitive detection and single molecular analysis will be possible by use of nanobiodevices, because of the large surface to volume ratio and the use of extremely small volume, such as fL and aL. Nanobiodevices are also suitable for single molecular and single cellular manipulation, since laminar flow, which is characteristic of low Reynolds number (Re) micro- and nano-fluidics, is valuable for separation and manipulation of single biomolecules and single cells, and it is possible to fabricate the nanostructure and nanomaterials, of which the size is comparable to the size of biomolecules and cells. Nanomaterials, such as quantum dots, which have quantum confined effects, are essential to develop highly bright and long life fluorescence materials even in the near infrared region, which will be indispensable for molecular imaging and intra vital imaging.

More recently, several strategic trends, including Advanced Manufacturing Partnership (USA), Industrie 4.0 (Germany), Made in China 2025 (China), and Society 5.0 (Japan), have been proposed. These strategies have been focused on the cyber and physical integration to realize the smart factory and the super smart society. Based on these strategic trends, the global companies have introduced new strategic technology concept, digital twin, which is a dynamic software model of a physical thing or system. Using physics data on how the components of a thing operate and respond to the environment as well as data provided by sensors in the physical world, a digital twin can be used to analyze and simulate real world conditions, responds to changes, improve operations and add value. Within three to five years, billions of things will be represented by digital twins. Davos meeting (world economic forum) selected internet of nano things (IoNT) as top 10 emerging technologies to achieve this strategic technology concept. Nanobiodevices integrated with AI will realize the IoNT and digital twin for society 5.0; super smart society.

We devolved nanobiodevices for biomedical applications and society 5.0, including single cancer cell diagnosis for cancer metastasis, circulating tumor cell (CTC) detection by microfluidic devices, nanopillar devices for ultrafast analysis of genomic DNA and microRNA, nanopore devices for single DNA and microRNA sequencing, nanowire devices for exosome analysis, single-molecular epigenetic analysis, AI-powered IoNT sensors, quantum switching intra vital imaging of iPS cells and stem cells, and quantum technology-based cancer theranostics. Immuno-wall microfluidic devices realized the fast and low invasive "from blood to analysis" type biomarker detection of cancer with fM detection sensitivity within 2 min. Additionally, nanopillar nanofluidic devices give us ultrafast electophoretic separation of DNA and microRNA within 1 ms and nanopillar-nanopore integrated nanobiodevice enables us ultarafast single molecular DNA sequencing. Nanowire devices coupled with super-resolution optical microscopy are extremely useful to analyze extracellular vesicles from cancer cells and vesicle-encapsulated microRNA analysis. The device composed of a microfluidic substrate with anchored nanowires gives us highly efficient collections of extracellular vesicles in body fluids and in situ extraction huge numbers of miRNAs (1016 types) more than the conventional ultracentrifugation method. Nanowire-nanopore devices combined with AI, machine learning technique enable us to develop mobile sensors for PM2.5, bacteria, and virus in the environment. Quantum dots are applied to develop quantum-biodevices for single cancer cell diagnosis, single molecular epigenetic analysis, quantum switching intra vital imaging for iPS cell (induced pluripotent stem cells) based regenerative medicine, and theranostic devices for cancer diagnosis/therapy. Quantum dots conjugated with transferrin are developed for brain tumor cell imaging.

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