

The 16th U.S.-Korea Forum on Nanotechnology: Nanosensors Related to Human Cognition and Brain Research & Nanomedicine Focusing on Single Cell Level

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Adopted on September 24, 2019

The first decade of the 21st century has been flourished by the advent of nanotechnology convergence and its application in a broad spectrum of science and technology areas along with multidisciplinary research initiatives to achieve rapid advancement toward 4th industrial revolution. To further promote development of new technologies, the United States (National Science Foundation, NSF) and Korea (Ministry of Science and ICT, MSIT) have been encouraging a common platform for the exchange of ideas and research collaboration in nanotechnology through these Forums, set up by the recommendations made by the Korea-US joint committee on Scientific and Technological Cooperation, held on October 31, 2002 in Seoul, Korea.

Ever since then, our Forums have been extremely successful, thriving over a decade of their organization history and promoting tremendous development in nanotechnology. These Forums have been a testimony to the transformative power of identifying a concept or trend and laying out a vision at the synergistic confluence of diverse scientific research areas. Our Forums have successfully provided a common platform for effective networking between research communities and industries in both countries by identifying emerging areas in nanotechnology which generate huge impact. This is evident from major collaboration initiatives between US and Korea, established via our Forums. Organizing the Forums has significantly expedited the generation of cutting edge technologies for the thrust areas in both countries. These Forums have been publicized through Carnegie Mellon website: <http://www.cmu.edu/nanotechnology-forum/>.

With this mission, we established the 1st U.S.-Korea Forum on Nanotechnology, via NSF funding, on October 14th-18th of 2003, in Seoul. As the Korean counterpart to NSF, participation was overseen and funded by MSIT. The topics in the subsequent Forums were recommended by the advisory committee members depending on the need of both countries at that time, and the locations of these Forums have alternated between Korea and the US. We organized the 2nd Forum, on nanomanufacturing research and the development of educational programs covering the field of nanotechnology. The 3rd Forum focused on active devices and systems research, unlike the passive systems studied during the first two Forums. We held the 4th

Forum, where the focus was on the sustainable nano energy with emphasis on the design and characterization of materials as well as devices and systems for energy applications. The 5th Forum focused on the emerging area of nano-biotechnology emphasizing novel nano-biomaterials, instrumentation technologies, and integrated systems for overcoming critical challenges in biomedicine and delivery of healthcare, as well as their environmental, health & safety (EHS), and toxicity issues. The 6th Forum dealt with nano-electronics with emphasis on fundamentals as well as integration with applications including convergence technology with biotechnology. The 7th Forum oversaw discussions ranging in nanotechnology convergence over current and future energy technologies to provide environmentally friendly solutions to the crippling challenges facing the energy sector. These seven Forums culminated in a seamless developmental and feedback process documenting the advent of nanotechnology convergence in broad spectrum of science and technology areas, for the first decade of the 21st century (NANO1). The 8th Forum in 2011, on nanotechnology convergence in sustainability, heralded new horizons in nanotechnology for the next decade (NANO2) by addressing critical problems faced by an ever increasing global population, with an emphasis on environmentally friendly technologies for the future on nanotechnology for sustainability, focusing on water reuse and desalination, greenhouse gas capture and conversion, and sustainable natural resources. The 9th Forum focused on channeling nanotechnology to the masses to responsibly address broad societal challenges such as nanoscience fundamentals, sustainability, and state-of-the-art applications for the new generation of nanotechnology products. The 10th Forum focused on laying out a roadmap for a new generation of nanotechnological products and processes. The 11th Forum focused on a new paradigm in nanomanufacturing, nanocomposites, and nanoinformatics. This Forum provides an opportunity to realize the potential of nanotechnology through the development of innovative and sustainable nanomanufacturing technologies for producing novel strong, light and smart nanocomposites and their management via nanoinformatics which will likely lead to paradigm shifting next generation enhanced performance of products in a broad range of existing industries including aerospace, automotive, energy, environmental remediation, information, and power industries as well as development of new industries. The 12th Forum focused on laying out a roadmap for a new paradigm in nanoscience-convergence in 2-D materials and for water purification via exploring improvements to technological tools for the application of nanotechnology and functional and novel nanomaterials to water-related topics. The 13th Forum focused on a new paradigm in nanoscience-convergence in brain-inspired (neuromorphic) computing and water & energy. The 14th Forum focused on laying out a roadmap for a new paradigm in nanoscience-convergence including nanosensors and neuromorphic computing. The 15th Forum was focused on laying out a roadmap for a new paradigm in nanomedicine focusing on single cell level as well as continuing effort on nanosensors including Internet of Things (IoT) devices.

The present 16th Forum was held at University of California San Diego, California, USA on September 23&24, 2019, and 60 eminent scientists and policy makers in the field of nanotechnology attended. This Forum focused on realizing the promise of nanotechnology through the development of nanomedicine focusing on single cell level and sensors related to human cognition and brain research.

To explore discussions on nanotechnology convergence further, we intend to organize the 17th Forum on September 21&22, 2020 to be held at Daejeon, Korea.

The topics include two emerging themes: sensors related to human cognition and brain research as well as confluence of nanotechnology and artificial intelligence. We believe that the continuation of the nanosensor area during the 17th Forum will further promote collaboration between scientists in the both countries and will identify concrete collaboration topics and teams. For the past three years, consecutive-year discussions on the same topics, which includes neuromorphic computing (13th and 14th Forums), nanosensors including IoT (14th and 15th Forums), and nanomedicine (15th and 16th Forums), had been great success.

The followings are recommendations made by the two subgroups during this Forum:

■ Sub-group 1: Sensors related to human cognition and brain research

Technical Topics of Interest to both US and Korea Research Communities and Challenges

1. Single Cells

- Development of single cell interrogation technologies with consideration of biotoxicity, long time functionality (stability), and addressing issues of perturbation to normal function as well as biofouling.
 - One potential approach is to standardize the characterization techniques for each technical topic, and write reports/papers so that the community is aware of the standard to properly vet nanotechnology and delineate the hype from real.
- Continue to pursue multimodal approaches for interrogation (optic, electric, magnetic, and acoustic) and enable chronic monitoring with single cell resolution.
- Expand new technologies for cell type-specific interrogation.
- Scaling up the technology of single cell sensors.

For multimodal and large data sets from scaled technologies, leveraging machine learning and approaches from multidisciplines is critical to properly interpret and synthesize information.

- Interfaces between artificial and individual ‘organic’ nerves to provide urgent repair of nerve damage and then complement with chemical and biological approaches. Use artificial nerves to control soft robotics with minimal energy.

2. Intact Brains

The development of multi-channel distributed wireless systems for large coverage, minimal invasiveness, etc. for clinical and scientific research applications, while involving physicians and regulatory people.

Pursuing miniature technologies that can cross the blood brain barrier, and benefit from modalities to allow this (acoustic/ultrasound). DARPA already started investing \$100M program in non-invasive brain mapping. Smaller scale projects for multiple teams may lower risk and increase innovation.

Pursue technology integration for example of nanoscale technology with magnetic modality with readily accessible MRI.

3. Wearables

Wearables for human machine interfaces are already in deployment but may need decades of optimization and improvement in the following:

- Area of coverage, hair problems, power, bandwidth, etc. that are being addresses with printed electronics, self-assembly, better IC design, better energy harvesting and storage, but still need further development.
- Inclusion of data processing/machine learning on wearable device and only upload significant data to the cloud may relax some of the above requirements → Multidisciplinary approach.
- The development of higher spatial specificity wearable for controlling machines → potentially leveraging other modalities than electrical to access deeper tissue.
- The development of sensitive and electrochemically stable intra-oral wearables and ingestible devices.
- Integration of on-skin wearables and under-skin implantable devices.

Recommendation

- Find Resources (\$\$) to support collaboration and student exchange.
 - More funding... → more funding → more and more funding!
 - There are currently a few joint collaborative project opportunities, but much more

resources need to be set aside to fund many instead of only a handful of projects to nurture diverse innovations and ideas rather than investing in a handful.

- The priorities for both government funding are very similar. Maybe allocate a separate pot of funding for joint projects in these areas.
- Create joint US-Korea mini-symposia after large meetings to facilitate exchange of ideas and collaborations.
- Create more time for discussions during the US-Korea Forum by potentially making the poster session at one evening during/after dinner.
- Discuss more logistics of collaboration including ownership of projects, IP issues, and how the government and institutions can facilitate these interactions among simple and rapid MOUs.

■ Sub-group 2: Nanomedicine focusing on single cell level

Current challenges:

- Collaboration culture in Korea (engineering ↔ medicine)
 - Frequent interaction among experts with multidisciplinary backgrounds
 - Institute-organized, top-down approach
 - Personal connection is the driving force but it interferes the achieving translation goal.
 - Asan and other institute: institute matches collaborators
 - It is difficult to communicate engineers to medical doctors
- Cornell
 - 4 hour driving distance (engineering and clinic) → physical proximity is important
 - Students spend 6 week in clinic and go back to engineering campus
- Communication gap
- Korean colleges really push physician researchers
- Entrepreneurship support
 - Korea: Death Valley of nanomedicine maybe caused by the lack of translation(company establishments)
 - The culture is changing because of government support for biomedical area
 - organized interactions among scientists and investors helped to form startup companies (trust-building)
 - NSF funding mechanisms
 - SBIR
 - iCORP (\$50k)

- partnership for innovation (\$600k):
https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504790
- Small business grant in Korea is too small to commercialize a technology
- Collaborative attitude is important (being respectful and patient)
- Venture capital money, space, collaborations, communication gaps
- SKKU: Samsung support (IP issues)
- Biomedical device development require longer lead-time (higher hurdle)

Support needed from the government (policy makers) / Suggestions

- Mechanism to train trainees for the future
 - Suggesting training programs for graduate students to have two mentors
- Incentivize
 - Top-down: student training program or funding mechanism bringing multidisciplinary fields together, institute pushing clinicians to do research
 - Human Frontier
 - Grant-writing boot-camp and 1 proposal selection at the end of the symposium
 - Poster session first for introduction?
 - Brainstorming grant ideas and circulate CVs or research description/Area seeking for collaboration prior to the Forum
- Student exchange programs
 - NSF funded fellowship similar to <https://www.whitaker.org/>
 - Graduate students from Korea to US
 - supplementary funding for US student to visit other country for collaboration is already available from NSF
 - NSF INTERN program: <https://www.nsf.gov/pubs/2018/nsf18102/nsf18102.jsp>
 - US-Korea Nanomedicine school similar to International school of nanomedicine (<https://nanomib.wixsite.com/nanomedicineschool>)
- To promote entrepreneurship drive
 - Korea: Clear regulation guidance and fast adoption of US FDA dialog is needed
 - NSF-FDA partnership program (supplement funding)→ testing early on to test in FDA labs: <https://www.nsf.gov/pubs/2018/nsf18556/nsf18556.htm>
 - Peer-success story (MIT, Stanford, Bay area or Boston) and institutes' interest should be shift towards
 - Ending question: How can we encourage young Korean to become entrepreneur?