Grand Challenge Research on Bio-Activated Transportation – Integration from Nano to Micro

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Current MEMS and microfluidic designs require external power sources and actuators to drive the local motion within the micro-environment. This principally limits such kind of emerging technology. However, similar activities have been developed in biological system for thousand of years. In detail, cellular activities such as intercellular mass transport, cell division and various forms of cell motility and contractility are all driven by biomolecular motors. It is intriguing to employ the nanoscale biomolecular motors into the microfluidic device. Among various biomolecular motors, for example, conventional kinesin (now referred to as kinesin-1) holds significant potential for nanotechnology applications because it is compact (the actual motor domains are < 10nm), efficient (~ 50%), moves robustly in vitro, and extracts chemical energy from its aqueous working environment. Kinesin generates linear, stepwise motion along microtubules (a filamentous cytoskeletal polymer) toward their plus-end by alternately advancing its two motor domains in a hand-over-hand manner. Each of the resulting 8-nanometer steps is coupled to the binding and hydrolysis of one molecule of adenosine triphosphate (ATP). As the consequence, it is possible to implement the biomoelcular driven microfluidic devices by designed manner.

Of particular significance for future nanotechnology applications of biomolecular motors are strategies to effectively interface with and extract sufficient mechanical power from this nanometer-scale machine. However, the force generated by a single kinesin molecule is miniscule (~ 5 - 6 pN) and needs to be scaled up to drive man-made microstructures. In nature, cells generate large forces and substantial mechanical power by utilizing highly ordered arrays motor proteins. For example, in skeletal muscle cells myosin motors and actin filaments are precisely aligned in the nearly crystalline structure of the sarcomere to harness the collective forces (up to one hundred newton) and motion (up to 10 m/s) from a very large number ($>10^{13}$) of individual motor molecules. We need to follow nature's strategy and develop new technology to selectively pattern and functionally integrate kinesin molecules and microtubules into engineered microstructures. As the direction of

motion of kinesin motors along microtubules is determined by the structure (polarity) of the microtubule and directed towards its plus-end, the most critical and challenging requirement is to uni-directionally guide, sort and align microtubules such that they can serve simultaneously for many motors as nanoscale tracks. Accordingly, micrometer-scale structures may be driven by kinesins along such aligned microtubule tracks to generate meaningful motion and mechanical power. However, the detail mechanism has not been identified yet. As the consequence, there are plenty of rooms existing for research based on basic understandings and innovative designs.