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学 位 論 文 内 容 の 要 約

博士の専攻分野の名称　博士（理学）　氏名　タマンナ　イスラット　ファルハナ

学 位 論 文 題 名

Study on the Effect of Physical Properties of Microtubules on their Collective Motion by Kinesins
（微小管の集団運動における物理特性の影響に関する研究）

The collective motion is an entrancing display of the coordinated behavior of the self-propelled particles, which is often associated with formation of fascinating large-scale patterns. Examples of this complex self-organization process is common in nature, exhibited by a wide range of self-propelled objects ranging from human crowds, animals, birds, cells, bacteria, to subcellular cytoskeletal filaments. The details study of collective motion may provide us insight into the emergent structures, and function which consequently will allow us obtaining information about how to assemble a large number of collectively moving self-propelled objects to more ordered structure with a view to application in technology and molecular robotics. In silico works significantly contributed to much of our understandings of the coordinated behavior and pattern formation by the self-propelled objects. A suitable experimental system has long been awaited for demonstrating the collective motion in vitro in order to verify the mechanisms of collective motion and pattern formation suggested by the in silico works. In recent years biomolecular motor systems F-actin/myosin, microtubule/dynein, and microtubule/kinesin have emerged as ideal candidate for experimentally demonstrating the collective motion through in vitro gliding assay. In this dissertation, the in vitro study on emergence of collective motion of microtubules driven by kinesin and effect of physical properties of microtubules on the collective motion have been summarized.

In chapter 1, the purpose of this dissertation and background of this research have been described.

In chapter 2, I have demonstrated the first-ever collective motion of microtubules on a kinesin coated surface using depletion force induced by a macromolecule (methylcellulose) in vitro. In this work, employing methylcellulose as depletant to induced depletion force, the probability of attractive collision between gliding microtubules has been regulated, which consequently allowed emergence of collective motion and finally resulted in pattern formation by microtubules. I have also explored the kinetics of collective motion of microtubule. I unveiled how the concentration of microtubules and depletion force affect the ensemble behavior of microtubules driven by kinesins. My experimental results suggested that both the concentration of microtubules and the depletant (methylcellulose) have important impacts in the kinetics of collective motion of the kinesin driven microtubules. Importantly the concentration of microtubules and the methylcellulose employed in the gliding assay also affect the time required to cause such a phase transition. These findings offer a simple and universal technique to investigate the coordinated behaviour of self-propelled objects using biomolecular motor systems.

In chapter 3, I have studied collective motion of microtubules having different mechanical property and found the emergence of streams and large spiral pattern by flexible GTP-microtubules and rigid GMPCPP-microtubule. The experimental analysis revealed that the mechanical property of microtubules has regulated the persistence length and extent of noise of movement of microtubule in the collective motion. According to theoretical predications,

the persistence length and extent of noise experience by the moving objects are the regulatory factors that can control the mode of collective motion. By experimentally verifying the theoretical models, a new approach has been established to regulate the mode of collective motion of self-propelled biomolecular system by changing the mechanical property of individuals. This work offers a novel way to program the self-organization of self-propelled objects, which ultimately will help us to design programmable molecular robots.

In chapter 4, I demonstrated the formation of an ultra large vortex pattern by collectively moving microtubules in response to external mechanical stress subjected by indentation. The obtained programmed vortex pattern of microtubules is advantageous over the other unprogrammed assembly of microtubules in means of size, directionality, and stability. The experimental results also suggested that, the kinetics of the formation of vortex pattern and orientation of the microtubules in the vortex depends on the induced stress filed, which is directly related to some geometric parameter, like indenter size, shape, and indentation depth. This study would allow us to understand the group behavior of self-propelled particles experiences external perturbation.

In chapter 5, all the important outcomes and future prospects of this research work have been discussed. In this dissertation, I have presented in-details study on the collective motion of kinesin driven microtubules, which offers a better understanding of the coordinated behavior of other self-propelled systems in nature alongside in understanding the insight into emergent structures obtained through a non-equilibrium process. Moreover, recently microtubule/kinesin system has attracted attention in the field of molecular robotics as the smallest self-propelled objects. Molecular robots, relying on a large number of collectively moving self-propelled objects such as gliding microtubules, enables parallel processing in transporting a large number of small cargos and assembling building blocks into an ordered structure. The outcome of this dissertation approaches to a concept of programing the self-organization of cytoskeletal filaments through changing their mechanical property which not only provides us with a means to program the active-self organization of self-propelled particles also will be helpful to understand the dynamics of active matters in nature. Therefore, the ideas obtained from the presented research work collective motion of microtubules are expected to expand the boundaries in the field of molecular robotics.