論文 / 著書情報
Article / Book Information

題目(和文)	タンパク質分子針の動的挙動考慮設計による自己集合構造の創出
Title(English)	Dynamics-coupled Design of Protein Needles for Constructing Self-assembly Structures
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出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第12662号, 授与年月日:2024年3月26日, 学位の種別:課程博士, 審査員:上野 隆史,石井 佳誉,金原 数,田口 英樹,三重 正和
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第12662号, Conferred date:2024/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Outline of
Dynamics-coupled Design of Protein Needles for Constructing Self-assembly Structures

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2024 Feb

In this thesis, I demonstrated the design of hierarchical self-assembly structures in hybrid systems based on the dynamic behaviors of proteins. This thesis consists of 5 chapters. Chapter 1 overviews the backgrounds of protein assembly designs and their dynamic assembly mechanisms. Despite the extensive studies, there remains a missing link between the design based on static structures and the dynamic behaviors inherent in proteins. Thus, I set out to establish protein needle-based assembly designs coupled with dynamic behaviors. Chapter 2 establishes a foundational framework, linking dynamics and design through the design of protein needles (PNs). Tailored protein-protein interactions led to distinct assembly structures on mica, such as straight fibers and triangular lattices. Real-time high-speed atomic force microscopy (HS-AFM) observation and Monte Carlo simulation underscored the significance of diffusive motions in achieving proper assemblies. This chapter demonstrates the bridging of protein design, dynamic behaviors, and assembly formation, leveraging the high designability and trackability of PNs. In Chapter 3, I designed a head-tail asymmetric protein needle called gp5_CHis to achieve more complicated assemblies. HS-AFM imaging and analyses revealed that gp5_CHis exploits two distinct protein interactions orthogonally to form a mica-specific tetrameric network-like assembly. Chapter 4 explores optically functional materials via a protein-hybridized system. I fabricated structurally colored films from cellulose nanocrystals (CNCs) and aimed to tune their color through protein incorporation. Although the detailed mechanism and further experiments should be addressed in the future, the results suggest potential approaches in protein-CNC hybrid systems for functional biomaterials. In Chapter 5, I provide the general conclusion and perspective, discussing the possible future directions of assembly designs harnessing dynamic functions.