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Development of Quantum-Enhanced Diamond Molecular Tension Microscopy: Towards Precise and Label-free Imaging of Cellular Forces

Principal Investigator (Hong Kong):
Professor Zhiqin Chu, Assistant Professor, Department of Electrical and Electronic Engineering, Faculty of Engineering

Project Summary:
Diamonds are known to be ever-lasting jewels with apparent colours intimately related to their internal impurities called color centers. For instance, the nitrogen vacancy (NV) centers bring a pink colour to diamond and, more interestingly, emits different spin-state dependent photoluminescence under microwave irradiation.

Here, by combining next-generation quantum measurement platforms, with innovative biointerface engineering technologies and advanced computational tools, the researchers propose an innovative approach, termed quantum-enhanced diamond molecular tension microscopy (QDMTM), for the accurate measurement of cellular forces. Specifically, they will conjugate the magnetic nanotags labeled, force-responsive polymer to the surface of diamond membrane containing NV centers, and the coupled mechanical information can be quantified through optical readout of spin relaxation of NV centers modulated by those magnetic nanotags. The established QDMTM will be utilised to investigate downstream bio-events, e.g., measuring the force transmitted by integrin-based cell-substrate adhesion as well as the cadherin-mediated cell-cell junction. Furthermore, the proposed platform will be further upgraded into a standardised toolkit allowing a wider accessibility.

The unprecedented sensitivity and precision of the proposed QDMTM will be inherently guaranteed by the quantum nature of using NV centers' spin degrees of freedom. In fact, this fluorescent label-free approach can in principle mitigate exisiting difficulties, like photo-bleaching, limited sensitivity, and ambiguities in data interpretation. If successful, the project, leveraging quantum physics, nanofabrication, material science and cell biology, can lead to a powerful tool that fundamentally impacts the way of how people study important issues like cell-cell or cell-material interactions and mechnotransduction.

港大「聯合科研資助基金計劃」項目

無標記精准細胞力成像的量子增強鑽石分子力顯微技術研究

首席研究員（香港）：
工程學院電機電子工程系助理教授褚智勤教授

項目簡介：
鑽石被認為是永恒的珠寶，其明顯的顏色與其內部雜質（稱為顏色中心）密切相關。例如，氮空位（NV）色心使鑽石呈粉紅色，更有趣的是，在微波輻射下，它會發射不同的自旋態依賴型光致發光。在此，通過將下一代量子測量平台、創新的生物界面工程技術和先進的計算工具相結合，研究團隊提出了一種創新方法，名為量子增強鑽石分子張力顯微鏡（QDMTM），用於精確測量細胞力。具體來說，研究人員將磁性納米標籤標記的，力敏感的聚合物與含有 NV 中心的鑽石薄膜表面偶聯，並且可以通過光學讀出被這些磁性納米標籤調節的 NV 中心自旋弛豫的機械信息。建立的 QDMTM 將用於研究下游生物事件，例如，測量整合素基質細胞 - 基質黏附以及黏附蛋白介導的細胞-細胞連接傳遞的力。此外，擬議的平台將進一步升級為標準化工具包，以實現更廣泛的應用。

擬議的 QDMTM 的前所未有的靈敏度和精確度將由使用 NV 中心自旋自由度的量子本質來保證。實際上，這種無標記的螢光方法原則上可以減輕現有的困難，如光漂白、靈敏度有限和數據解釋中的歧義。如果成功，這項目將利用量子物理、納米製造、材料科學和細胞生物學，成為一個強大的工具，從根本上影響人們研究細胞 - 細胞或細胞 - 材料相互作用和機械轉導等重要問題的方式。