Optical Imaging of a Single Molecule with Subnanometer Resolution by Photoinduced Force Microscopy

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Visualizing the optical response of individual molecules is a long-standing goal in catalysis, molecular nanotechnology and biotechnology. The molecular response is dominated not only by the electronic states in their isolated environment but also by neighboring molecules and the substrate. Information about the transfer of energy and charge in real environments is essential for the design of desired molecular functions. However, visualizing these factors with spatial resolution beyond the molecular scale has been challenging. Recently, a new optical microscopy concept (photoinduced force microscopy: PiFM) [1], which detects the intensity distribution of near-field light localized on a material surface as a force, has attracted much attention as a method to study the local optical response of materials. The dipole–dipole interaction between the dipole induced by the tip and the dipole induced by the sample surface is measured as a photoinduced force. The local optical responses of materials can be visualized with high spatial resolution because the photoinduced force is inversely proportional to the fourth power of the tip–sample distance. Since PiFM is based on atomic force microscopy (AFM), the structure of the sample surface, including insulator surfaces, can be observed, and the charge transfer (or change in the contact potential difference (CPD)) of the sample can be measured by using Kelvin probe force microscopy (KPFM). PiFM is an ideal experimental platform for studying the optical response of materials at the nanoscale, which has not been previously investigated in detail.

Here, by combining PiFM and KPFM, we have mapped the photoinduced force in a pentacene bilayer with a spatial resolution of 0.6 nm and observed its 'multipole excitation' for the first time [2,3]. We identified the excitation as the result of energy and charge transfer between the molecules and to the Ag substrate. These findings can only be achieved by combining microscopy techniques to simultaneously visualize the optical response of the molecules and the charge transfer between the neighboring environments. Our technique and findings open up the possibility of designing molecular functions from the optical response at each step of stacking molecules layer by layer.

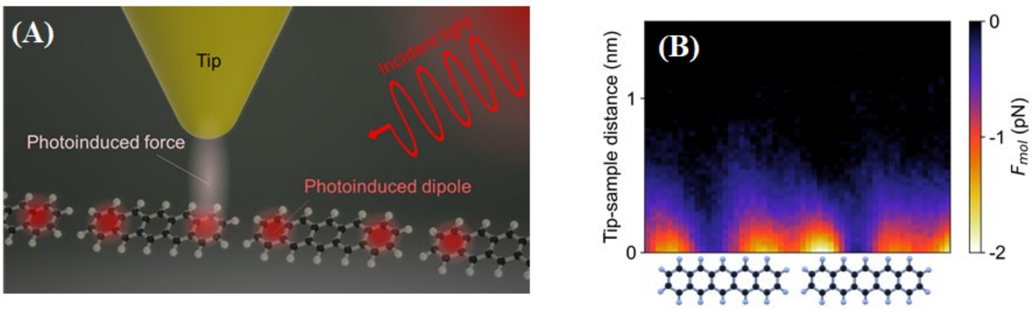

Figure 1. (A) Configuration of the photoinduced force microscopy system and (B) results of 2D mapping of photoinduced force of a pentacene molecule.

References

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