Optical and transport properties in molecular nanosystems observed by STM-based techniques

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For the real progress of nanotechnology, it is indispensable to develop novel methods that can measure various physical and chemical properties of nanostructures by accessing each structure directly. From this point of view, we have developed specialized scanning tunneling microscope (STM) techniques to investigate various functionalities of nanostructures. By use of these STM techniques we evaluated and controlled functions of the molecular nanosystems fabricated on solid surfaces. In order to put the obtained information by these techniques to practical use, we verified to fabricate prototypes of electric and optical devices.

1.- Evaluation of electric transport properties in organic molecular layers

Basic science interest and potential applications in large-area, flexible electronic systems motivate research in the filed of organic semiconductors. So far, many works aimed an understanding charge transport in organic semiconductor systems, but a well developed, microscopic investigation is still lacking. We have constructed a novel method based on STM, an independently-driven double-tip scanning tunneling microscope (DT-STM) system[1-2], which has two independently-operated tips. The two tips are used as point contact electrodes to test the performance of various prototype of organic nanoscale electric/electronic devices. We performed the direct measurement of two-dimensional electrical conductance and mobility of molecular thin films in the range of micrometer region using DT-STM. We also obtained the pronounced anisotropy of the mobility of a pentacene single crystal using DT-STM and successfully correlated the mobility anisotropy with the molecular crystal structure for the first time [3]. In addititon, we fabricated nanogap flat electrodes with smooth boundaries between metal electrodes and an insulating substrate for the purpose of evaluating the electrical transport properties of a single molecule and molecular assemblies. We proposed a simple fabricating procedure that combined a lift-off process containing electron beam lithography and reactive ion etching with a mechanical grinding process. By use of the nanogap flat electrodes, high mobility in nanoscale organic-thin-film FET has been realized [4].

2.- Optoelectronic property measurement for organic molecular nanosystems

The photophysical properties of organic molecules/thin layers have been extensively investigated because of their potential applications in the field of photonics, and organic photo/electroluminescence devices. We have investigated the optoelectronic characteristics of nanomaterials, in particular, organic molecular nanosystems by use of STM-induced light emission (STM-LE) analysis [5]. Tunneling electrons from STM were used to excite photon emission from nanostructures on the surface, and the high spatial resolution of STM enables a demonstration to evaluate light emission spectra from organic molecular nanosystems in nanometer scale. Surface plasmons in the interface between a metallic/dielectric medium generate an intense electromagnetic field on the metal surface, which provides an efficient enhancement field for some optical processes. Recently, we have reported plasmon-enhanced copper phtalocyanine (CuPc) fluorescence on an Au(111) substrate by STM-LE. The quantum efficiency of the intrinsic fluorescence of CuPc is very low; however, the plasmon enhancement effect on an Au surface extensively increases fluorescence efficiency.

Considering a prospect of applications to use the plasmon enhancement effect, we fabricated a thin film organic light emission diode (OLED) on a trial base, and investigated the enhancement of electroluminescence by surface-plasmon-coupled emission [6]. Through the use of Au nanoparicles embedded in the hole transport layer, the emission intensity was increased significantly, indicating that Au nanoparticles effectively increase the internal quantum efficiency of an OLED owing to the strong coupling of excitons with localized surface plasmons of Au nanoparticles.

References

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