【Grant-in-Aid for Scientific Research (S)】

Science and Engineering (Interdisciplinary Science and Engineering)

## Title of Project : Advanced Single-Atom Spectroscopy

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Research Project Number : 16H06333 Researcher Number : 00357253
Research Area : Interdisciplinary Science and Engineering
Keyword : Electron microscopy, Individual atoms, single molecules, Low-dimensional materials

### 【Purpose and Background of the Research】

It has remained a challenge for scientists to see and identify individual atoms since Dalton first proposed distinct atoms in his atomic theory in 1800. Recent development of electron microscopes has enabled us to obtain spectrum from individual atoms by providing an atomically small electron probe and a high-performance spectrometer. In this project, we aim to develop the single atom spectroscopy technique for higher performance with higher sensitivity, higher precision and higher efficiency so that one can monitor changes in spin state or oxide state of single atoms. The project will contribute to the fundamental researches in the wide field such as physics, biology, chemistry and materials.

### 【Research Methods】

The following three research theme are proposed, (i) High-speed chemical map to track individual atoms, (ii) High-precision spectroscopy for single atom electron states, and (iii) in situ spectroscopy to detect fine structure changes in near-edge fine structure for single atom spectrum. To realize them we improve the environments of TEM, chromatic aberration of lenses, stability and brightness of electron source and performance of spectrometer.

### 【Expected Research Achievements and Scientific Significance】

(i) Tracking individual atoms in chemical map leads to understand the dynamics of lattice defect that is a key for device properties in low-dimensional materials. (ii) High-precision single-atom spectroscopy allows us to detect single atoms at higher reliability and the wider elements detectable in the periodic table. It is important to get spin/oxide states of wider range of elements, especially for transition atoms or noble atoms. (iii) *in situ* ELNES measurements allow to monitor chemical reaction or phase transformation at atomic level. Especially, a molecule in which Fe atom locates its center is known to react oxygen and the spin state of Fe atoms is claimed to be a key to catch or release the oxygen molecules. One will be able to monitor such a biological activity at single atom basis.

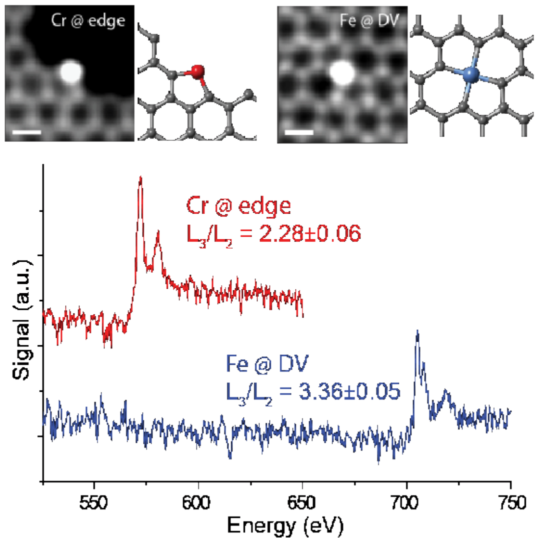


Figure. Single atom spin state spectroscopy. The branching ratio of *L*-absorption edge does correspond to the charge transfer between d-subbands of specific 3d transition metals. Here in the figure above, a Cr atom at graphene edge and a Fe atom at divacancy (DV) in graphene both show a high-spin state judging from the measured $L_{23}$ branching ration.

### 【Publications Relevant to the Project】

・K. Suenaga et al., "Element-selective single atom imaging" *Science* 290 (2000) pp. 2280-2282
・K. Suenaga and M. Koshino, "Atom-by-atom spectroscopy at graphene edge", *Nature*, **468** (2010) pp.1088-1090

### 【Term of Project】 FY2016-2020

### 【Budget Allocation】 130,900 Thousand Yen

### 【Homepage Address and Other Contact Information】

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