Single atom spectroscopy by low voltage STEM

K. Suenaga[1],

1. Nanotube Research Center, National Institute of Advanced Industrial Science and Technology, AIST Central 5, 305-8565 Japan

E-mail: suenaga-kazu@aist.go.jp

Reducing the accelerating voltage of TEM/STEM is becoming essential when one aims to image any light element matters and/or beam sensitive objects. Lower acceleration voltage is beneficial to enhance the image/EELS contrast as well as minimize the knock-on effect which heavily destructs the atomic structures. In order to compensate the poor spatial resolution due to the low acceleration voltage, more sophisticated electron optics are definitely required to reduce the residual geometric/chromatic aberrations.

Under a JST project, namely the triple C project, Sawada et al. designed a new type of Cs corrector with triple dodecapole elements (the DELTA system) to reduce the six-fold astigmatism [1, 2], which is very advantageous for the TEM/STEM operated at low accelerating voltages around 15 to 60 kV. A JEOL 2100F equipped with this corrector shows a world best performance in terms of the spatial resolution normalized by the wave length, which was proved by the Si (224) reflection (111pm) corresponding to the 16 times of the used wave length (□□= 7 pm at 30kV) [3]. This is a clear proof that the atomic resolution can be achievable in STEM-ADF mode even at 30kV. One of the major advantages of low voltage TEM/STEM has been demonstrated by chemical analysis of individual molecules without massive structural destruction [4, 5]. We have employed a spectrometer dedicated for low-voltage operations (GIF Quantum, modified).

In this presentation, I summarize our recent progresses of low-voltage TEM/STEM within the scheme of triple C project. The current status of our monochromator and aberration corrector developments will be shown. The examples for atomic defect and edge analysis of low-dimensional materials, such as graphene, h-BN, MoS_2, as well as 1D atomic chains [6,7,8], will be also presented.

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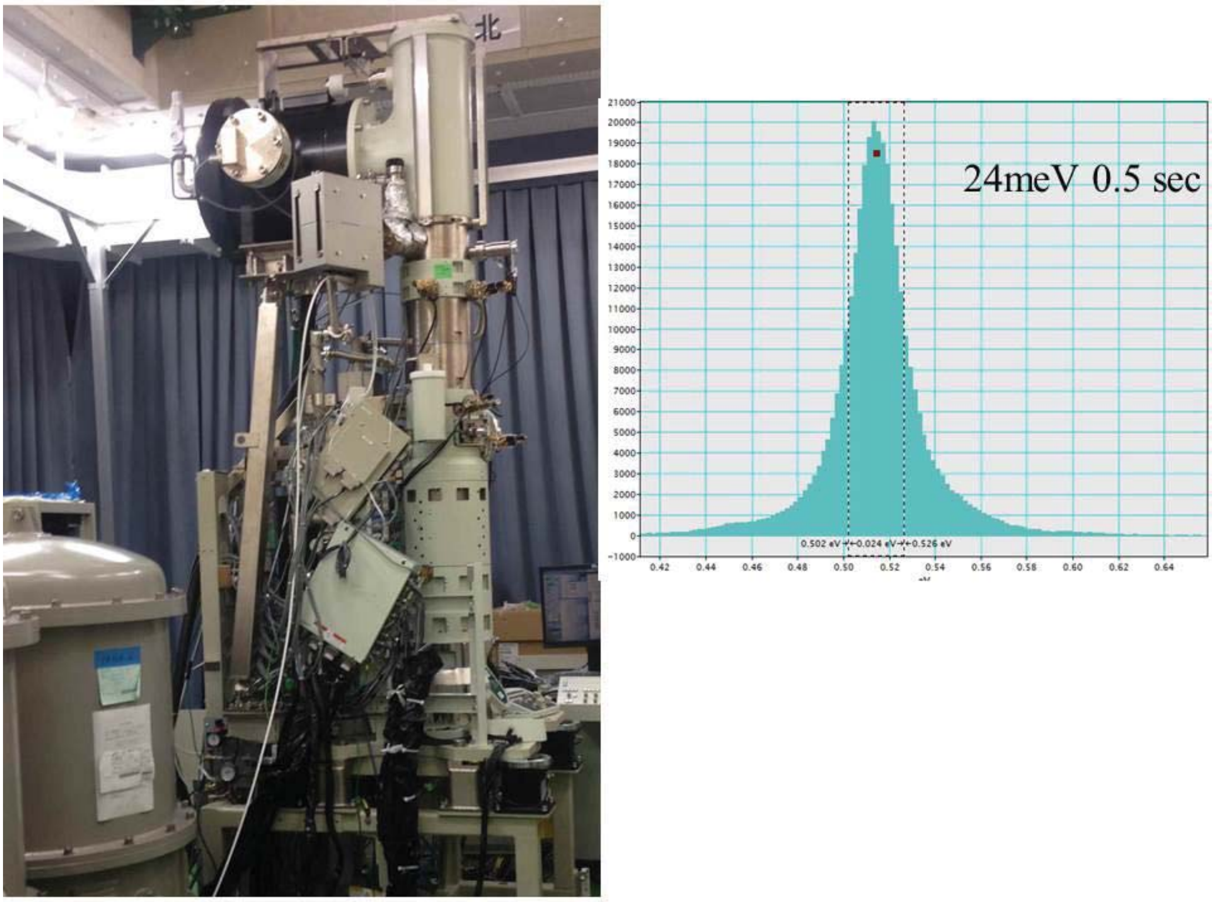

Fig. 1. Monochromated LV-TEM/STEM with Delta correctors and LV-GIF, showing routinely 25 meV energy reolution. Callaboration with Drs. Mukai, Sawada, Treavor and Gubbens.