# Development of Electrostatic Actuated Nano Tensile Testing Device for Mechanical Characterization of Carbon Nanowires

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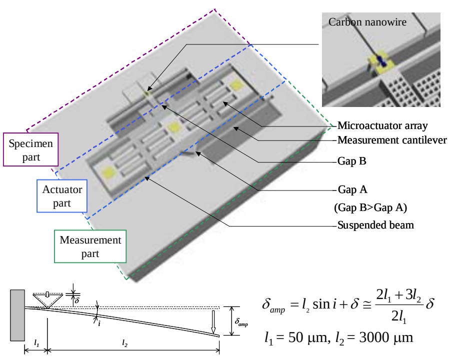
## Objective

Understanding mechanical properties of carbon nano structures deposited by the FIB-CVD is of use in reliable and optimum design of carbon integrated nano electromechanical systems (NEMS).The objective of this research is to evaluate mechanical properties of carbon nanowires deposited by the FIB-CVD at room temperature. This research developed <u>E</u>lectrostatic <u>A</u>ctuated <u>NA</u>no <u>T</u>ensile testing devices (*EANATs*) using MEMS fabrication techniques.

## Experimental Procedure

### Design layout of *EANAT*

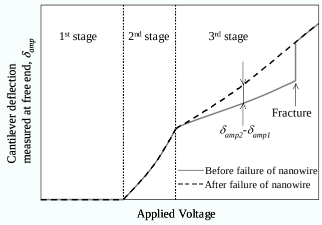



$$\delta_{amp} = l_2 \sin i + \delta \cong \frac{2l_1 + 3l_2}{2l_1}\delta$$

$l_1$ = 50 µm, $l_2$ = 3000 µm

Lever motion amplification system

### Measurement method of tensile loading




Relationship between cantilever deflection at free end and applied voltage to comb drive actuators

$$P = (k_1 + k_2 + k_3) \times \frac{(\delta_{amp2} - \delta_{amp1})}{91}$$

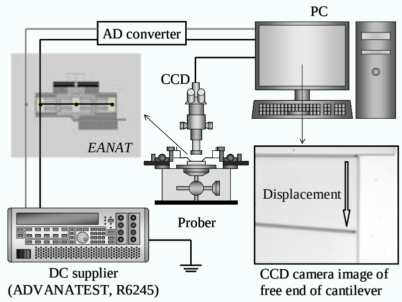
*P*: tensile load
$k_1$: spring constant of suspended beams in actuator part
$k_2$: spring constant of cantilever
$k_3$: spring constant of suspended beams in specimen part

1st Stage
- Actuator part is separated from Specimen part. (Gap B)
- Actuator part is separated from Measurement part. (Gap A)

2nd Stage
- Actuator part is separated from Specimen part. (Gap B)
- Actuator part comes into contact with Measurement part.

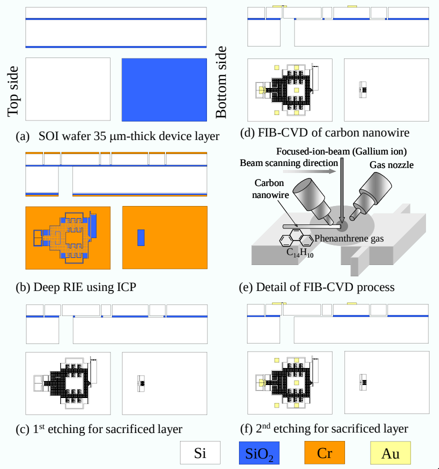
3rd Stage
- Actuator part comes into contact with Specimen part.
- Actuator part comes into contact with Measurement part.

### System diagram of tensile testing setup with CCD camera system



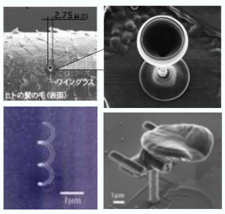

Displacement resolution: 0.29 nm
Force resolution: 123 nN to 450 nN

### Fabrication process of *EANAT*



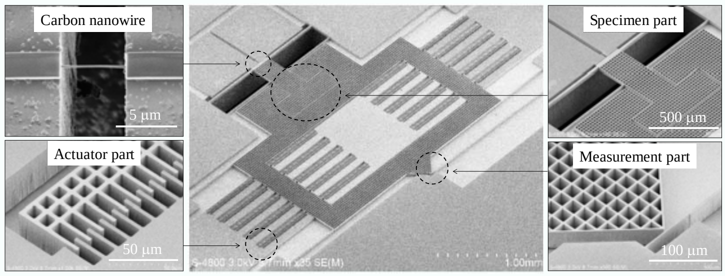

### FIB-CVD


Focused Ion Beam / Scanning Ion Microscope

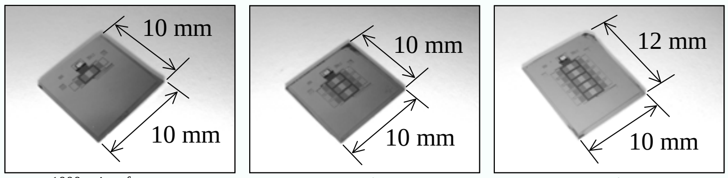


Ref. S. Matsui, et.al. J. Vac. Sci. Technol. B21(6), Nov/Dec 2003,
Laboratory of Advanced Science and Technology for Industry, University of Hyogo

### Photographs of *EANAT*



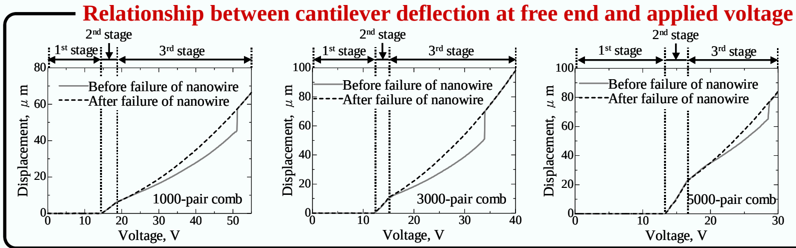

*EANAT* with 1000 pairs of comb drive actuators




1000 pairs of actuators | 3000 pairs of actuators | 5000 pairs of actuators

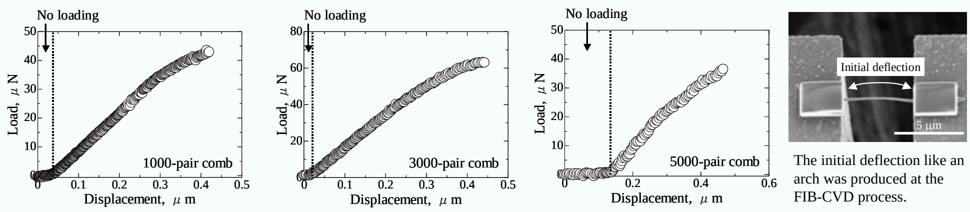
## Results and Discussions

### Relationship between cantilever deflection at free end and applied voltage to *EANATs*



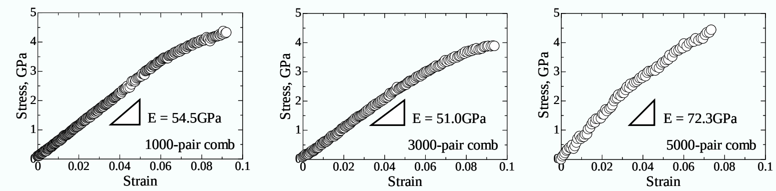

Three stages of variation in the cantilever deflection have been recognized in all figures.
Each tensile load of nanowires is derived from differences in deflection between before and after failure of nanowires at 3rd stage.

### Load-displacement curves of carbon nanowires



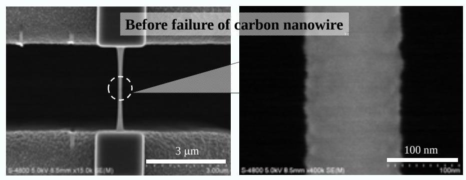

The initial deflection like an arch was produced at the FIB-CVD process.

### Stress-strain curves of carbon nanowires

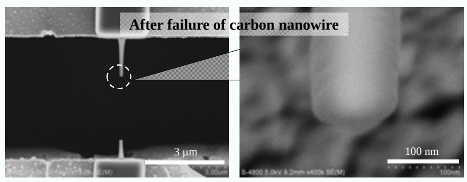



Young's modulus: 58 GPa.
Fracture stress: 4.2 GPa
Fracture strain: 0.08
The high stiffness of the FIB deposited carbon nanowires would be sufficient to use as a nanometric structural material in NEMS.

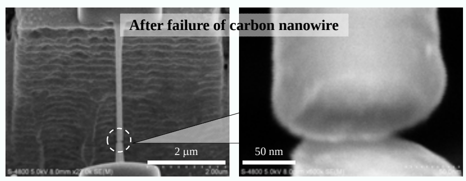
### FE-SEM photographs




The uneven surface on a nanoscale is observed at the center of the nanowire. The flare gas would have also formed carbon clusters on the nanowires.




The fracture surface has the smooth and rounded edge at the breaking points. Fracture of the nanowire would have been promoted by localized contractile deformation initiated from the uneven surface of the nanowire.




The development of *EANATs* has enabled us, for the first time, to reveal deformation and failure mechanisms of the FIB deposited carbon nanowires under uniaxial tensile stressing.