The three-dimensional nanofabrication technology using focused-ion-beam

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Focused-ion-beam chemical vapor deposition (FIB-CVD) enables fabrications of the three-dimensional (3-D) nano- and microstructures. We have been researching on nanofabrications using FIB-CVD in order to achieve the 3-D functional devices. FIB-CVD is carry out by controlling the irradiation time and position of Ga^+ FIB under supplying source gas molecules, as shown in Fig. 1. Secondary electrons generated by FIB irradiation onto the substrate dissociate the source gas molecules, such as *phenenthrene* ($C_{14}H_{10}$) and *tungsten hexacarbonyl* ($W(CO)_6$), and nanostructure is deposited on the substrate. Then, we can fabricate the 3-D nanostructures by controlling the irradiation position of FIB, as shown in Figs. 2(a) and 2(b).

Thus far, we have researched on the growth characteristics and pattern generator in order to fabricate arbitrary nanostructures. As a result, we enabled the fabrication of the ultra-long over-hang structure by developing a pattern generator with the real-time feedback control system, as shown in Fig. 2(c). In addition, we evaluated that the material characteristics and modified them to obtain the functional material characteristics for the device development. We found that diamond-like carbon structure (DLC) deposited by using *phenanthrene* ($C_{14}H_{10}$) as source gas has the superior mechanical characterisitics. Also, piezoresistive property which is a useful material characteristics for the device development was added to DLC nanocantilever structure by annealing treatment. Furthermore, the fabrication of the functional mechanical devices was researched, as shown in Figs. 2(d) and 2(e). Nanomanipulation of nanoparts was achieved by nanomanipulator with the 3-D four fingers. And, the wavelength measurement with a high resolution of 2.2 pm was demonstrated by an optomechanical resonator with plasmonic fin nanostructures. The 3-D nanofabrications by FIB-CVD enables us to create novel functional devices.

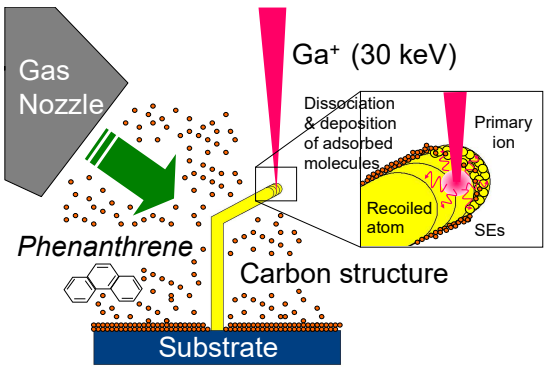

Fig. 1 Schematic of The 3-D nanostructures fabrication using FIB-CVD

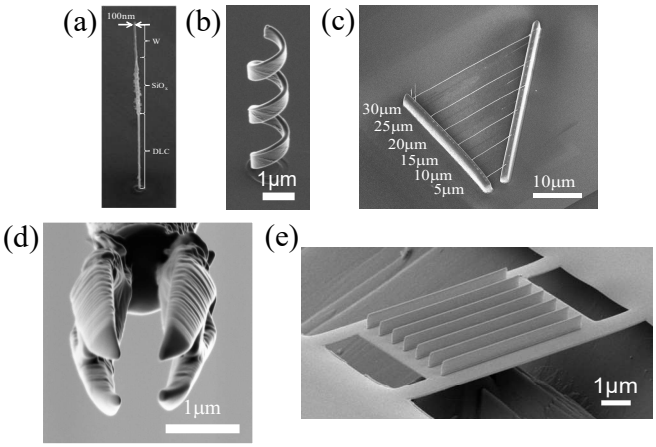

Fig. 2 The 3-D nanostructures and devices: (a) $W/SiO_2/DLC$ hetero pillar structure, (b) ultra-long air-wire nanostructure, (c) nanospring, (d) nanomanipulator, (e) optomechanical resonator