1. Introduction

Carbon nanomaterials, represented by carbon nanotubes and graphene, have unique characteristics, such as extremely high carrier mobility, optical transparency, and mechanical flexibility, which are difficult to replicate with silicon devices. These properties promise applications in new types of electronic devices. For future device applications, advanced structure control is needed over the diameter and orientation of nanotubes, the layer numbers and edge structure for graphene. In this program, we have aimed at the realization of such new field of “carbon electronics”.

2. Carbon Nanotubes

In carbon nanotube research, the control of the position and orientation, as well as control of the chirality which determines the electronic structure, are both extremely important issues. In 2005, we found the horizontally aligned growth of single-walled nanotubes (SWNTs) on single crystalline sapphire surface in a self-assembled manner. We further developed this finding and achieved highly controlled growth of SWNT arrays by patterning catalyst on the sapphire surface (Fig. 1(a,c)). We also succeeded in bending a SWNT during growth and growing in two orthogonal directions (Fig. 1(b)). The semiconducting SWNT showed a good transfer device performance, as shown in Fig. 1(d). Furthermore, with the aim to control the nanotube chirality, the chemical vapor deposition (CVD) growth of nanotubes have been thoroughly studied, and we proposed a new route to tune the nanotube diameter via ultrahigh vacuum annealing of metal nanoparticle catalyst. Based on the near infrared photoluminescence measurements, we found an interesting surface dependence of SWNT chirality (Fig. 1(e)), which can be further developed to the chirality control.

Summary:

Nanocarbons have attracted a great interest because they show unique physical properties and promising electronic applications that are different from conventional carbon materials. In this study, we investigated new methods to control the structures of graphene and carbon nanotubes to develop carbon-based circuits and flexible devices.
3. Graphene

Graphene is a relatively new material obtained by mechanical exfoliation of graphite in 2004. Recently, the CVD growth has been widely used to synthesize large-area, transferrable graphene with relatively low cost. Usually, a polycrystalline metal film is used as a catalyst, as shown in Fig. 2(a), but it gives polycrystalline graphene consisting of a large number of small domains due to the polycrystalline nature of the metal. The presence of domain boundaries existing in polycrystalline graphene significantly reduced the carrier mobility and mechanical strength. Therefore, in our study, a metal film epitaxially deposited on a single crystalline substrate is used as a catalyst for the graphene growth, as illustrated in Fig. 2(b). Accordingly, we obtained a very high quality uniform single-layer graphene with controlled hexagon orientation for the first time. The photograph of the transferred graphene is shown in Fig. 2(c) together with the diffraction pattern from graphene. Furthermore, we revealed that the domain structure of single-layer graphene is strongly dependent on the crystalline plane of the metal catalyst from the studies of the Cu(100) and Cu(111) catalysts (Fig. 2(d,e)). More recently, to form a bandgap in graphene, we have developed new methods to synthesize or pattern graphene nanoribbons. We have also extended our study to graphene-on-rubber in order to develop a novel type of flexible devices (Fig. 2(f)).

4. Conclusion

Nanocarbons are new carbon materials with unique electronic, mechanical, and thermal properties which promise applications in many fields and lead to effective use of carbon source. Our pioneering research is now supported by the JSPS funding program for Next Generation World Leading Researchers (NEXT Program), and it is our earnest desire to make progress with further research in the future.

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