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단 신

대나무 형 탄소 나노튜브에 의한 탄소나노튜브 섬의 연결

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Interconnection of Carbon Nanotubes Islands by Bamboo-Like Carbon Nanotubes

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Electrical properties of carbon nanotubes could be varied as metallic, insulating, or semiconductor depending on their diameter, wrapping angle, or post-growth treatment.[1-4] Due to their unique electrical properties and geometries, thus, carbon nanotubes have been regarded as the high potential materials for the nanoelectronic device, such as the single electron transistor.[5-7]

For the nanoelectronic device, the patterning of the device and the interconnection between cells would be essential. Recently, the pre-mature patterning technology has been reported by the selectively partial growing of the carbon nanotubes on the substrate via the pre-patterned catalyst.[8-10] For the interconnection line, indeed, the metallic characteristics carbon nanotubes can be imagined as an optimal material because of its fascinating shape suitable to connecting with nanometer diameters and micrometer lengths, high electrical conductivity and excellent mechanical strength. Until now, merely a few attempts to make nanotubes interconnection lines have been succeeded.[11-13]

This work presents one of the possible techniques to achieve the interconnection between the isolated carbon nanotubes cells. We made the nickel catalyst in patches on the substrate and grow the carbon nanotubes under the high negative bias voltage condition. Finally, we achieved the formation of the carbon nanotubes islands and the bamboo-like carbon nanotubes interconnection lines between the islands.

EXPERIMENTAL SECTION

Nickel catalyst coating on silicon substrate could be achieved by radio frequency (RF) sputtering system. In RF-sputtering experiment, we used Ar gas with 30 mTorr total pressure under 500 W RF power condition. The thickness of nickel on silicon substrate is about 100 nm after 10 min sputtering. After depositing nickel layer, we cut the substrate and made the nickel coated 1.0×1.0 cm^2 silicon substrate.

For the sporadically as-deposited nickel catalyst, we etched the nickel layer by the bias-induced plasma, which has 99% hydrogen and 1% methane gas composition, in a horizontal-type microwave plasma enhanced chemical vapor deposition (MPECVD)

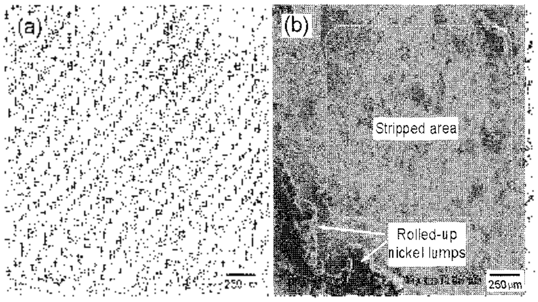

Fig. 1. SEM images of (a) the surface of the nickel coated silicon substrate and (b) the surface of the etched substrate.

system. The detailed experimental conditions for the etching are as follows. Microwave power=500 W, flow rate of H_2=99 sccm, flow rate of CH_4=1 sccm, substrate temperature=900 °C, total pressure =80 Torr, bias voltage = -400 V and reaction time=1 min. In this way, we could successfully obtain the nickel catalyst in patches on the substrate (See *Fig.* 1).

For the carbon nanotubes deposition, we pre-cleaned the substrate with pure H_2 plasma for a few minutes without bias application before the deposition reaction. After pre-cleaning the substrate, we introduced 5% CH_4 in H_2 flow. The detailed experimental conditions for the carbon nanotubes deposition were shown in *Table* 1.

The detailed morphologies of carbon nanotubes were investigated by using field emission scanning electron microscopy (FESEM).

RESULTS AND DISCUSSION

After 10 min nickel deposition on the silicon substrate and 1 min 99% hydrogen plasma etching the substrate, we first compared the surface images between the as-deposited nickel coated silicon substrate and the etched substrate. By comparing *Figs.* 1a with b, we understand that the 1 min 99% hydrogen plasma etching can give rise to severely damaged surface of the substrate. The nickel layer-stripped area and the large size rolled-up nickel lumps could be well observed (see *Fig.* 1b). Indeed, the nickel layer could not be much damaged merely by the pure hydrogen plasma. Therefore, the cause for the severely etched results was believed to be due to the high negative bias voltage application during the etching process. Namely, the high negative bias voltage could initiate the driving force to strongly induce the hydrogen ion onto the surface. And then, the nickel layer of the substrate surface might be damaged by the incoming hydrogen ion and etched away. Consequently, it can show the worn-out surface images as shown in *Fig.* 1b. Even in the nickel layer-stripped area, we could observe that very tiny lumps of the Ni catalyst were sporadically dispersed (see the stripped area of *Fig.* 1b). We suggest that they may play a catalytic anchor role for the formation of carbon nanotubes islands.

After investigation the surface morphology, we put the etched substrate in the reactor and carried out the carbon nanotubes deposition. *Fig.* 2 shows SEM images of carbon nanotubes on the etched substrate. *Figs.* 2a and b show the formation of the carbon nanotubes islands on the substrate at the position of the sporadically dispersed nickel catalyst. In *Fig.* 2b, we can observe the peculiar-type, namely bamboo-like type, carbon nanotubes existence in the islands. The bamboo-like carbon nanotubes show linear shape. Most of the bamboo-like carbon nanotubes have longer linear length and thicker thickness than any other carbon nanotubes. This result indicates that the growing of the bamboo-like carbon nanotubes would be faster than any other carbon nanotubes under this reaction condition. Even though we couldn't understand the exact reason as to why the growth of the bamboo-like carbon nanotubes were dominant under this reaction condition, we suggest that the cause for the enhancement of bamboo-like carbon nanotubes density under the high bias voltage application condition may be attributed to the variation of the induced temperature of the substrate surface caused by the applied

Table 1. Experimental conditions of carbon nanotubes formation

Microwave power	Source gases	Flow rates of source gases	Substrate temp.	Total pressure	Reaction time	Bias voltage
600 W	CH_4, H_2	CH_4: 3 sccm, H_2: 57 sccm	900 °C	80 Torr	5 min	- 400 V

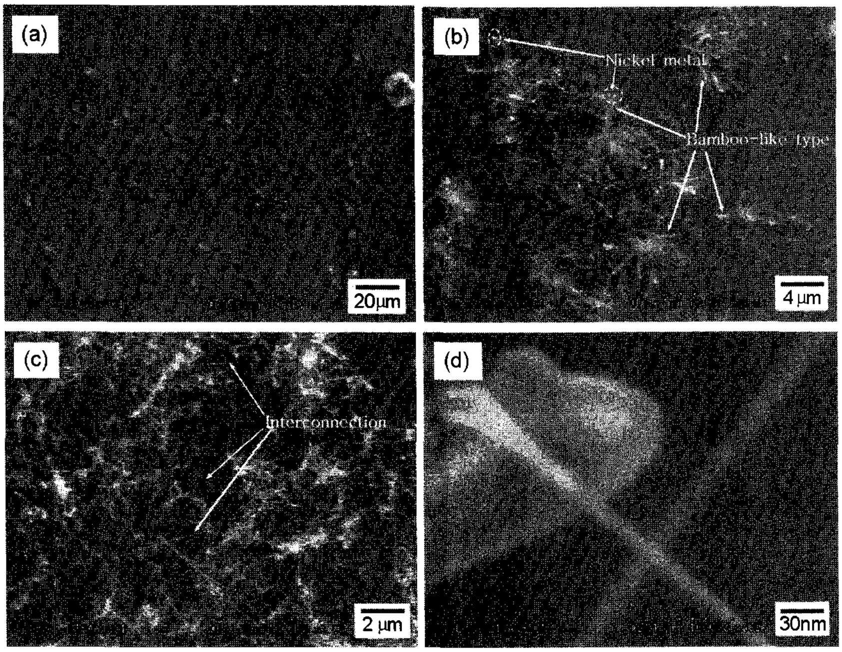

Fig. 2. Various SEM images of carbon nanotubes on the etched substrate: (a) the carbon nanotubes islands, (b) the magnified image of *Fig*. 2a, (c) the interconnection of the islands by the bamboo-like carbon nanotubes and (d) the high-magnified image of *Fig*. 2c.

high bias voltage. The high bias voltage application induces high temperature of the substrate surface. Previously, it was reported that a new structural formation to CNTs-like morphology was developed by the high temperature thermal annealing.[14,15] So, we suggest that the formation of the bamboo-like carbon nanotubes seems to favor the high-induced temperature of the substrate surface.

Fig. 2b also shows the metal existence at the head of the bamboo-like carbon nanotubes. So, we may suggest that the growing mechanism of the bamboo-like carbon nanotubes follows the metal-top growth mechanism with the nickel capped on the top-end position of carbon nanotubes.[14]

Due to the higher linear growth rate, the bamboo-like carbon nanotubes seem to be a good choice to use for the interconnection lines. *Fig*. 2c shows the interconnection between the carbon nanotubes islands by the bamboo-like carbon nanotubes. The bamboo-like carbon nanotubes act like an interconnecting highway between the carbon nanotubes islands (see the arrow position in *Fig*. 2c). Noticeably, most of the bamboo-like carbon nanotubes connected to the carbon nanotubes themselves, instead of the substrate (see *Fig*. 2c). This result reveals that the self-assembling nano-interconnection seems to be possible via the bamboo-like carbon nanotubes interconnection.

Fig. 2d shows the high-magnified image of the bamboo-like carbon nanotubes. As shown in *Fig*. 2d, the diameter of the bamboo-like carbon nanotubes would be larger than 10 nm, indicating the multi-walled type. Although we couldn't exactly measure the electrical characteristics of the bamboo-like carbon nanotubes, the straight shape of the bamboo-like carbon nanotubes may have an advantage for the pathway of the electronics. Judging by the appearance, thus, the bamboo-like carbon nanotubes look like a good electrical characteristics material. Electrical characteristics measurement regarding this material is underway.

CONCLUSIONS

We could achieve the interconnection of the carbon nanotubes islands by the bamboo-like carbon nanotubes. The high negative bias voltage application during the carbon nanotubes deposition reaction seems to be the main reason for the straight shape and high growth rate of the bamboo-like carbon nanotubes. The growth mechanism of the bamboo-like carbon nanotubes follows the metal-top growth mechanism. Most of the bamboo-like carbon nanotubes connected to the carbon nanotubes themselves, instead of the substrate, expecting the feasibility for the self-assembling nano-interconnection.

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