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Influence of Rapid Thermal Annealing on the Growth of Carbon Nanotubes and Their Emission Properties

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Since CNTs have high electron emission efficiency at low voltage due to their high aspect ratio, they have been regarded as the most efficient electron emitter among various materials. However, because of the shielding effect of the dense CNTs, it is necessary to control the diameter, length, and site density of CNTs for field emission[1,2]. Although the diameter and length of aligned CNTs can be easily controlled by the thickness of catalyst layer and growth time, it is not easy to control the site density[3]. The current methods used to decrease the density of CNTs are by reducing the catalyst metal density using micro contact printing, electron-beam lithography, photolithography and shadow mask[1,4,5]. However, the demerits of current methods are either expensive or inefficient in terms of control the site density in large area. In this study, we used rapid thermal annealing (RTA) treatment to form Ni nanoparticles to act as catalyst for CNTs growth.

10 nm-thick Ni was evaporated on the p-Si substrate with diffusion barrier layer SiO_2. RTA was performed to form Ni nanoparticles and the temperature was varied from 700 to 900℃ During annealing process, Ni thin layer was found to be breaking up into nanoparticles. After annealing process, CNTs were grown at 650℃ in the mixture gas of C_2H_2 and NH_3 by PECVD. Fig. 1 shows the surface morphology of Ni films is shown. An initial morphology of 10-nm-thick Ni film is extremely flat[Fig. 1(a)]. The morphology of Ni film annealed at 700℃ shows that Ni film is still agglomerating[Fig. 1(b)]. As RTA temperature increased from 800 to 900℃, an average size of Ni nanoparticles increased from 120 to 180 nm as shown in Fig. 1(c) and 1(d). The results shown in Fig. 1 demonstrate that the higher annealing temperature gives rise to the formation of isolated large-size islands. Fig. 4 is SEM images of CNTs which were grown by DC-PECVD at 650℃ for 15 min. Fig. 2(a) shows that the directly grown CNTs without RTA treatment have randomly oriented. But CNTs grown after RTA treatment have vertically aligned as shown in Fig. 2(b). Field emission properties of CNTs were characterized in vacuum of 4×10^{-6} Torr. A transparent glass plate coated with indium tin oxide (ITO) was used as anode and was separated from the CNTs layer by 80 μm. The area of ITO layer was fixed at 0.8 cm^2. The electron emission characteristics were obtained from the CNTs in Fig. 2(a) and 2(b). As shown in Fig. 3, the turn-on electric field of CNTs grown after RTA treatment reduced from 5.5 to 3.5 V/μm. It is apparent that we can obtain the more improved field emission properties from the well aligned CNTs.

In conclusion, we have shown that it is possible to obtain nano-sized Ni islands by RTA treatment. Compared with as-grown CNTs, the well aligned CNTs formed after RTA treatment have better field emission characteristics.

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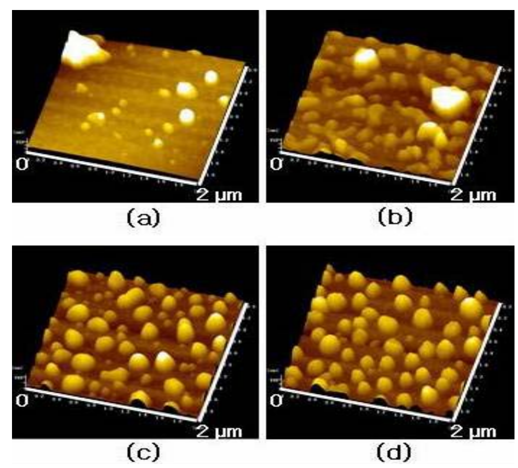

Fig. 1. AFM images of Ni islands formed by RTA treatment at various temperature. (a) unannealed, (b) 700℃, (c) 800℃, and (d) 900℃.

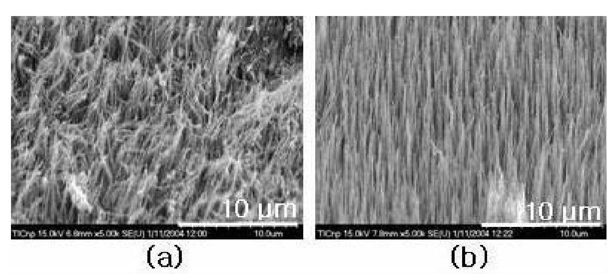

Fig. 2. SEM images of CNTs grown by PECVD at 650℃ for 15 min on the sample of (a) unannealed, (b) annealed at 800℃ for 50 sec.

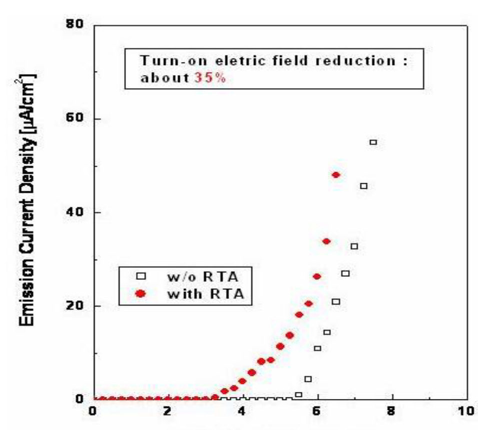

Fig. 3. Comparisons of field emission characteristics of CNTs grown with RTA treatment and as-grown CNTs.