A SEM Study on Space Environment Effects of Carbon Nanotube Arrays

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Abstract. Due to their unique properties, carbon nanotubes will have great potential applications in many fields, particularly in space applications. But in development of carbon nano-materials intended for operation in aerospace, one of the most important problems is assurance of their resistance against the impact of the AO which is one of the predominant environment in space. Here we present the AO erosion effects on pure carbon nanotube arrays by SEM analysis. It is shown that the morphologies of CNT arrays are quite different from those before AO experiments. Different morphologies of CNT arrays after AO exposure are shown by SEM images. It is presented that shrinkage and crack formation of CNT arrays are caused by bombardment force.

1. Introduction
Carbon nanotubes (CNTs) with extremely high strength, high stiffness, low density, good chemical stability, and high thermal and electrical conductivities will have great potential applications in many fields, particularly in space applications [1]. Atomic oxygen (AO) is considered the most erosive particle to spacecraft materials in low earth orbit (LEO), which can etch most materials of spacecraft. In development of carbon nanotubes intended for operation in aerospace, one of the most important problems is assurance of their resistance against the impact of the AO [2]. A few studies have been carried out to present the AO effects on CNTs[3-5], such as CNT composites, CNT wires and CNT films. We also have studied the AO erosion effects on CNT arrays [6, 7]. All these works focus on the erosion yields or the mechanical properties of CNTs in AO environment.

In our previous works, it was found that some “magic” patterns on CNT arrays had formed after AO exposure [6, 7]. As a stable nanotube foams, CNT arrays can be elastically deformed. Here we will give some more SEM analysis results, which may be helpful to understand the mechanics of AO erosion effects on CNT arrays.

2. Experimental method
As was reported before [7], well aligned CNT arrays were synthesized by a common method of chemical vapour deposition of ethylene gases in the presence of iron catalysts on the substrate of silicon. Three AO exposure experiments were carried out at Beijing Institute of Satellite Environment Engineering of China using an AO simulation facility. The facility produces a 5 eV neutral AO beam by placing a metal plate in contact with magnetically confined AO plasma. The AO plasma was produced.
by a microwave electron cyclotron resonance ion source driven by a 0.6 kW radio frequency at 2.45 GHz. The CNT array was placed on a holder in the AO simulation facility, and a directed AO beam impacted CNT arrays. The incident direction of AO beams was parallel to the radial direction of CNTs in the arrays. The AO flux was about $5.5 \times 10^{15}$ atom/(cm$^2$ \cdot s). The AO fluence was $1.5 \times 10^{20}$ atom/cm$^2$. The morphologies of CNT arrays before and after AO exposure were characterized by scanning electron microscopy (SEM, S-4800, Japan).

### 3. Result and discussion

Fig. 1 shows typical SEM images of CNT arrays before AO exposure, which have been reported before [7]. The surface of the as-grown CNT arrays is quite flat in macro-scale. After AO exposure, the surface of CNT array isn’t flat and continuous any more, and CNTs are completely etched away in some regions.

![Fig. 1 Overview images of CNT arrays before (a) and after (b) AO exposure.](image)

Some “magic” lines can be clearly seen as pointed out in Fig.2. It seems that these lines are higher than other zones. And the blank zones are located on the side of the lines. Few blank zones crossing the lines can be observed.
Fig. 2 “Magic” lines formed after AO exposure

Enlarged images show that the deformed surface of CNT arrays is like a mountain range (Fig. 3 a). There are many ridges and ravines. The “magic” line is relatively straight and continues, while other ridges are broken and continued. It shows that all the ridges are composed of compressed CNTs, on the top of which some amorphous carbon can be observed (Figure 3 b c). Along the “magic” line, there are some holes which may be the beginning of the blank zone formed during the AO exposure.

Fig. 3 Enlarge images of CNT arrays near “magic” line zone after AO exposure

We analyzed the morphologies of the “magic” line and other ridges carefully by SEM, but no difference had been observed. They all had shrinkage and crack formation formed by carbon nanotube aggregates, on the top of which some amorphous carbon could be observed. It is confused that how the “magic” line are formed and what’s the difference of the carbon nanotubes along the lines. It seems that the “magic” line is like a wall to resist the AO beams, and the blank zone in which all the carbon nanotubes are etched away can only extend to one side.
The edges of the blank zone are presented in Fig. 4. There are three typical morphologies as shown in Fig. 4 a b c. One is carbon nanotube slices standing straightly as indicated in Fig. 4 a. This phenomenon is non common. The other morphology is smooth edge as shown in Fig. 4 b. The edge is vertical to the substrate. The SEM image taken from the side of the edge shows that the CNTs are oriented and not be bended and condensed, which means that they are not damaged by AO beams yet (Fig. 4 c). Another morphology is carbon nanotube slices falling down toward the blank zone (Fig. 4 d). The sides of the slices would be impacted by AO beams. The SEM image confirms that the side of the slices is deformed by AO beams as shown in Fig. 4 e. Some big fibers composed of compressed carbon nanotubes play an important role in supporting the slices.

Fig. 4  SEM images of blank zones in CNT arrays after AO exposure

The formation of CNT arrays after AO exposure is a result of their unique properties and the bombardment effect of AO beams. It is known that CNT arrays are aligned, narrow spacing, high aspect ratios and flexibility. This indicates that AO bombard not only the surface but also the interior of the CNT arrays. When AO impacts on the wall of CNTs in the interior of the CNT arrays, the impact force would squeeze the CNTs on both sides. The surface of CNT arrays seems to have been cut apart. So a mountain range–like morphology has been obtained. Subsequently the AO would gather in the ravines, so the AO beam is like a beam knife to cut the CNT arrays. As a result, some slices are formed. Van der Waals interactions between condensed nanotubes are not the same in the whole CNT arrays, which may be the reason for different morphologies. And the low-density regions or vacancies of carbon nanotube
arrays may also play an important role in the formation of the pattern. But there are still some questions: why are there some “magic” lines appeared? What’s the different between the blank zone and other zone in CNT arrays?

4. Summary
The effects of AO on CNT arrays have been studied by SEM analysis. The morphologies of CNT arrays are also quite different from those before AO exposure. The deformed surface of CNT arrays is like a mountain range with many ridges and ravines. Some ridges (so called “magic” line) are straight and continue with all the blank zones beside them. The blank zones have different morphologies, which may be due to the different Van der Waals interactions between condensed nanotubes. Though many questions still exist, it is interesting to find out how an anisotropic material would change during AO beam exposure.

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