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Decontamination of surfaces exposed to single wall carbon nanohorns

Z. Karimi[a], P. Su[b], R. Oftadeh[a], H. Ebrahimi[a], R. Ghosh[a], A. Vaziri[a,*]

[a] Department of Mechanical and Industrial Engineering, Northeastern University, Boston, MA 02115, USA
[b] FM Global, Norwood, MA 02062, USA

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ABSTRACT

The effect of different surfactants on the removal efficiency of wiping surfaces contaminated with single walled carbon nanohorns (SWCNHs) was studied. To this end, sodium dodecylbenzenesulfonate (SDBS) and sodium dodecyl sulfate (SDS) surfactants were used, and their removal efficiencies with water only and with cleaning with a dry wipe were compared. The surfactant concentrations and wipe pressure during the wiping process were varied, and significant effects on removal efficiency were found. In addition, the results were compared with those obtained with single-walled carbon nanotubes (SWCNTs) and multi-walled CNTs (MWCNTs) and the differences among these nanostructures were reported. The results suggest that SDS and SDBS are good candidates for removal of SWCNHs deposited on silicon wafers with SDS removal efficiencies capable of exceeding 90%. In addition, the results show that there is an optimum wiping pressure and surfactant concentration with the highest removal efficiency. A direct relationship was also found between wipe saturation and removal efficiency of SWCNHs deposited on silicon substrates. The differences between individual nano structures were perceptible in spite of following similar broad trends; for instance, SWCNH contaminated surfaces in general proved more difficult to clean than surfaces contaminated with the other nanostructures.

1. Introduction

Carbon based nanostructures, including single walled carbon nanohorns (SWCNHs), single walled carbon nanotubes (SWCNTs), and multi walled carbon nanotubes (MWCNTs), have garnered tremendous interest in recent times due to their non-traditional properties. For instance, carbon nanotubes (CNTs) exhibit exceptional mechanical properties, unique electrical conductivity and high field emission characteristics [1–8]. SWCNHs, which were discovered a few years after CNTs, are about 40–50 nm in tubule length and about 2–3 nm in diameter. They are derived from SWCNTs and terminated by a five-pentagon conical cap with a cone opening angle of $\sim 19^{\circ}$ [9]. In contrast to CNTs, thousands of SWCNHs associate with each other to form 'dahlia-like' and 'bud-like' structured aggregates which have an average diameter of about 80–100 nm. Fig. 1 shows the transmission electron microscope (TEM) imaging of aggregation of these three types of carbon nanostructures: SWCNHs, SWCNTs and MWCNTs. Similar to CNTs, SWCNHs also hold tremendous possibilities for a wide range of potential applications such as energy management systems, medical applications such as drug delivery, gas absorption and synthesis of compound materials [10–12]. However, in contrast to the promise of high performance material behavior, these nano structures have also raised concerns regarding biological toxicity particularly due to their high surface to volume ratio, high reactivity and needle-like structures [13–18]. Thus, better control of nanostructure exposure and decontamination are an important goal for safe and convenient handling of these materials. Unfortunately, this task has proved to be challenging. For instance, removal of CNTs in case of accidental release in the work space can be difficult due to the strong adhesion between the CNTs and the substrate. This adhesion is caused by the high surface contact area and an external force is required to separate the CNTs from the substrate [19–21]. To remedy this undesired outcome, surfactants are widely used to disperse CNTs since they weaken the strong bond between particles using their inherent polarity. They also prevent the particles from re-adhesion, which is highly desirable for removal of CNTs from contaminated surfaces [22].

In this context, the ability of sodium dodecylbenzenesulfonate (SDBS) and sodium dodecylsulfate (SDS) surfactants to remove MWCNTs from rough surfaces was examined earlier [23]. Recently,

* Corresponding author.
E-mail addresses: vaziri@coe.neu.edu, a.vaziri@neu.edu (A. Vaziri).

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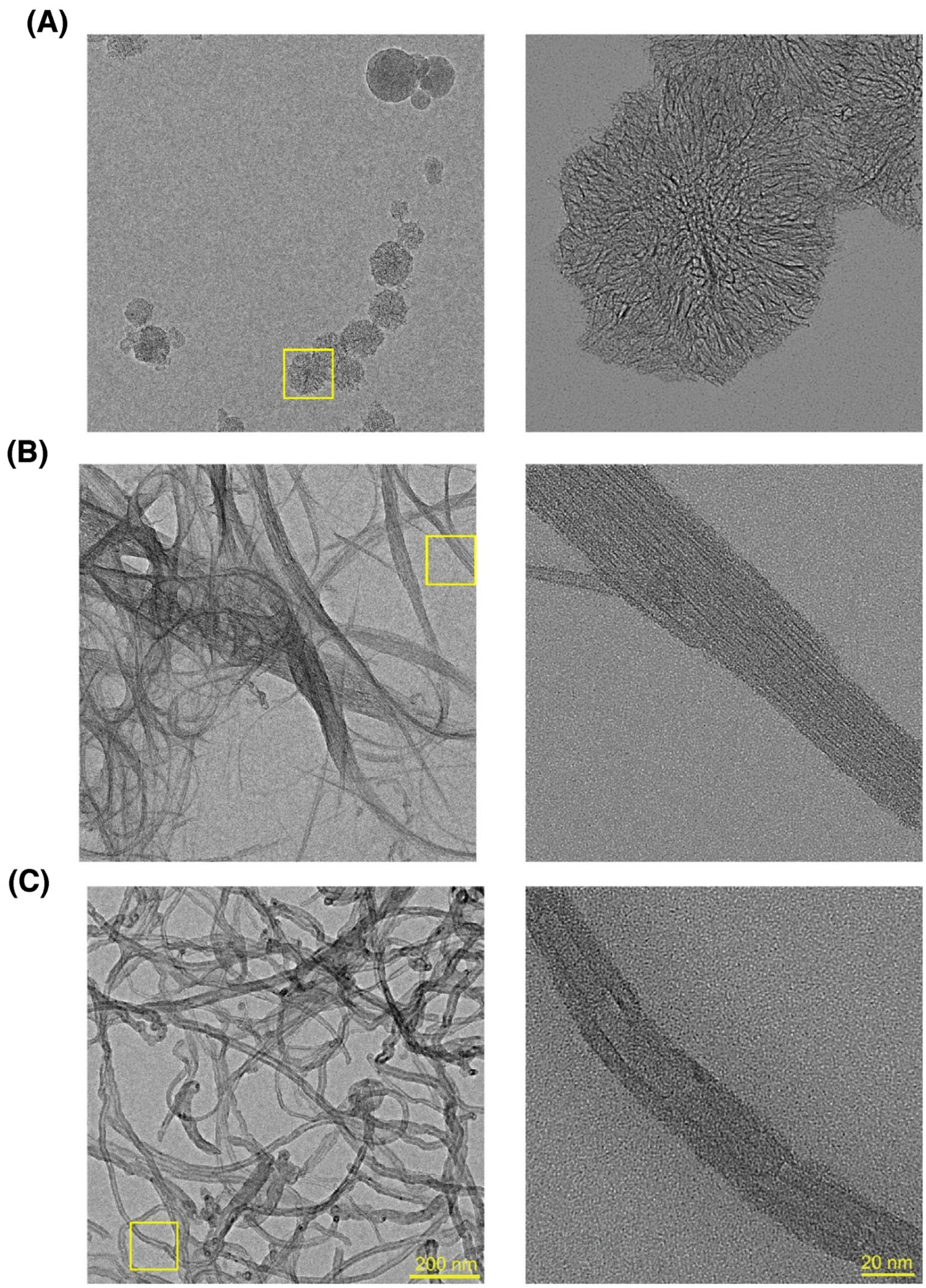

Fig. 1. (A) TEM imaging of aggregation of carbon nanohorns (diameter approximately 100 nm) (B) Aggregation of single walled carbon nanotubes (C) Aggregation of multi walled carbon nanotubes.

we examined the removal of MWCNTs from silicon wafers using various surfactants: SDS, SDBS, gum arabic and calcium carbonate ($CaCO_3$) [23]. The study showed the superior ability of surfactants to remove CNTs deposited on silicon wafers compared to cleaning with a dry wipe or cleaning with water.

In the current study, we determined the removal efficiency of SWCNHs from SWCNH-contaminated silicon wafers using pre-saturated wipes with different saturation percentages and different surfactant concentrations. The results derived for SDBS and SDS surfactants were compared with water and cleaning with a dry wipe. We also compared the behavior of SWCNH with two other common nanostructures, SWCNT and MWCNT. Finally, the effects of different surfactant concentration, saturation and pressure on cleaning wipes of two different types on the removal efficiency were examined.

2. Materials and methods

The MWCNTs and SWCNTs used for this study were combustion chemical vapor deposition (CCVD) grown and dispersed in polyvinylpyrrolidone (PVP) surfactant, whereas SWCNHs were produced using a continuous laser ablation method [23] and dispersed in ethanol. The average length of SWCNTs, MWCNTs and SWCNHs used in this study were 200 nm, 250 nm, and 45 nm and average diameters were 1.2 nm, 15 nm, and 3 nm, respectively. In the experiments, the nanostructures (CNTs and SWCNHs) were