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How Can the Nanomaterial Surfaces Be Highly Cleaned?

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1. Introduction

The induced contaminations (e.g polymer residues or impurities in air) on nanomaterial surfaces have been a serious problem to probe their intrinsic properties and for unique applications in surface chemistry, electronic, and optoelectronic. The polymer residues still presented on chemical vapor deposited graphene surface after its wet transfer (e.g. poly(methyl methacrylate) (PMMA)) on the arbitrary substrates tends to cause problems such as electrical degradation and unwanted intentional doping. Polymer residues (e.g PMMA), defects, and other contaminations are commonly leaving the thin layers or the particles as residues on nanomaterials.

Nowadays, the nanomaterials are receiving broad interests. Among them, grapheme [1-36], hexagonal-boron nitride (h-BN) [37-40], carbon nanotubes (CNTs) [41,42], and graphene oxide [43] are emerging as many promising potential materials with novel properties in electronics and optoelectronics (Figure 1). These nanomaterials have attracted a huge research interest in recent decades due to its anomalous properties such as very high carrier mobility, extremely high mechanical strength and optical transparency, electrical conductivity, chemical stability and thermal conductivity [1-43] and that is the reason above nanomaterials are being observed as a potential material for next-generation semiconductor devices that would replace silicon-based technology. Due to being an atomically thin material, every atom of nanomaterials has an access to surface that is directly responsible for its electronic and chemical activity. However, for many applications, the nanomaterials in pristine form cannot be used due to high resistance and performance degradation on poor nanomaterial quality.

Thereby, the exploration of new methods in order to mitigation as much polymer residues as possible on nanomaterials (CVD Graphene, CNT, GO, h-BN) is highly desirable (Figure 2). For instance on CVD graphene material, many reports have demonstrated to remove poly(methyl methacrylate) (PMMA) residues and other impurities on surface achieved the significant achievements such as wet chemical by acetone [25,26], cleaning by chloroform or toluene [44] by N-methyl-2-pyrrolidone [45] by diazonium salt [46] a modified RCA cleaning process and mechanically sweeping away the contamination [47] oxygen plasma and reactive ion etching treatment for a short time [25,26,46] mechanical method: AFM tip can remove all resist (theoretically without damaging the sample) in a contact mode [34] annealing in high temperature [18,25,26,48] current annealing [49] by acetic acid [50] by electrostatic force [16] by lithography resist [17] by annealing [18] by electric current [19] by electrolytic [20] by titanium sacrificial layer [22] by heat treatment in air and vacuum [23] by dry-cleaning [24]. Very recently, a superior technique for cleaning of nanomaterials using plasma (Ar, oxygen) proved extremely efficient in residue cleaning from graphene surface and tuning the graphene properties [25-29,51].

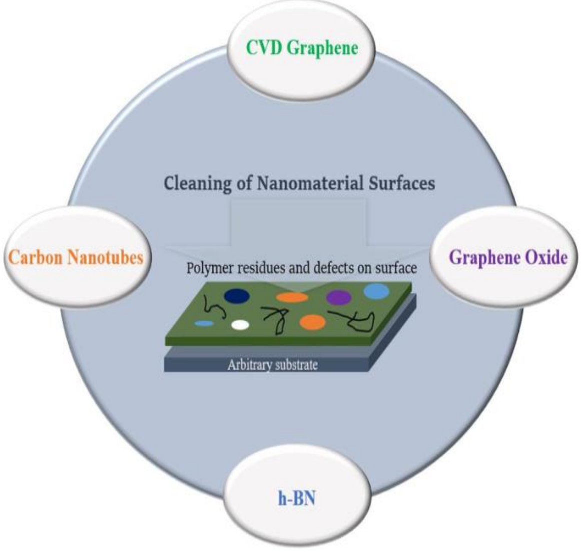

Figure 1.
Schematic of cleaning of various nanomaterial surfaces (CVD graphene, CNTs, GO, h-BN) by chemistry, physic, nanotechnology, and engineering for tuning their electronics and optoelectronics.

The cleaning of CNT materials surface by cyclic Ar plasma and nitric acid treatment for enhancing the electrical conductivity of flexible transparent conducting film [41] or by RF-PECVD technique [42] has also well-investigated. Or the surface of the h-BN material was cleaned greatly by wet chemical (HF solution) and annealing in vacuum at 10500C [52] or annealing at 4500C in air and ozone [40]. In addition, the contamination on GO surface was removed significantly assisted by an oxidation process and washing-centrifugation cycles which is controlled by pH of the supernatant.

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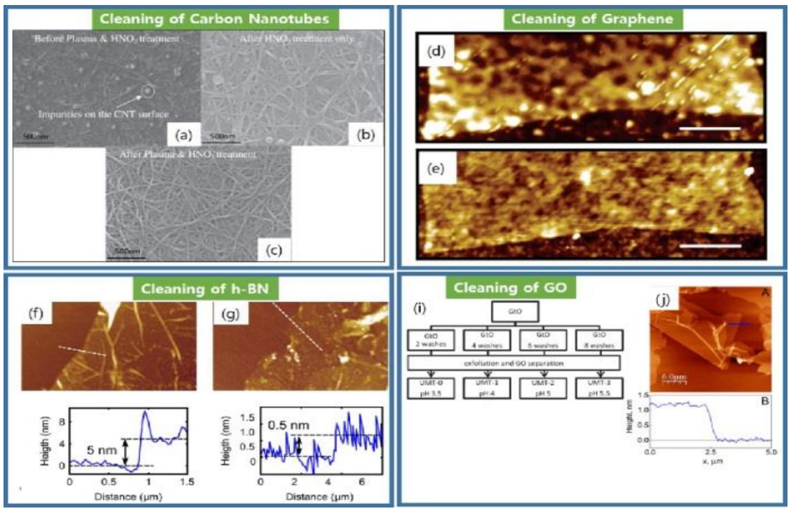

Figure 2.
Cleaning process of various nanomaterial surfaces such as carbon nanotubes (a-c), graphene (d-e), h-BN (f,g), and GO (i,j). (a-c) reproduced with permission from [41]. (d,e) reproduced with permission from [17]. (f,g) reproduced with permission from [40]. (i,j) reproduced with permission from [43].

The cleaning of nanomaterials (CVD Graphene, CNT, h-BN, GO) using various strategies related to chemistry, physic, nanotechnology, and engineering in order to obtain the ultra-clean material layer and resulting in improving their electrical characteristics is highly desiring with targeting toward practical applications in the industry to serve human society. The enhancing of electrical properties of cleaned nanomaterials would be raising up the current on-off ratio, photoluminescence, and other unexploited and unexplored exotic properties. Consequently, it could unlock and take a leap forward on developing superior plasma-based cleaning methods [15,32] for other TMDs and low-dimensional materials in various advanced devices and applications.

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