

Insights into Graphene-Based Sensors for VOC biomarkers of lung cancer: A DFT Perspective

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Summary:

In this work, we address key scientific questions regarding the use of graphene for lung cancer biomarker detection. The volatile organic compound (VOC) biomarkers of lung cancer were classified into nonpolar, polar with small dipole moments, and polar with large dipole moments. Using density functional theory (DFT) calculations, we examine the adsorption capacities of various VOC biomarkers on graphene surface. The analysis of binding energies provides valuable insights for designing sensitive and selective sensors for detecting lung cancer VOC biomarkers using graphene, potentially advancing early diagnosis and treatment of this disease.

Keywords: graphene, volatile organic compounds, lung cancer, density functional theory, adsorption.

Background and Motivation

Volatile organic compounds present in exhaled human breath and/or biofluids e.g., blood can be considered as bioindicators of lung cancer [1]. There are at least 22 polar or non-polar VOCs [2, 3] that discriminate between healthy and lung cancer patients. Many studies have been dedicated to the detection and identification of VOCs of lung cancer by using conventional techniques, such as gas chromatography, mass spectrometry, radiography, tomography, cytology, and fluorescence bronchoscopy [4-6]. Yet, these methods encounter significant challenges: i) time-intensive breath analysis; ii) non-portable screening equipment; iii) high costs; iv) limited sensitivity to small lung cancer tumors and picomolar VOC concentrations. Recent efforts focus on finding gas-sensitive materials capable of detecting picomolar VOC concentrations linked to lung cancer. Conductive polymers, metal oxides, carbon nanotubes, gold nanoparticles, and graphene-based nanomaterials (GBM) have shown promise in developing sensing platforms [7-9]. GBM, in particular, holds great potential for commercializing affordable, rapid, and reproducible sensors for biomolecule identification. Such an enhanced potential of these materials in biosensing field is governed by the unique properties of GBM (huge carrier mobility, high electrical conductivity, high signal-to-noise ratio, large surface area of 2630 m²/g, high electron-transfer rates, and

low toxicity) [10]. These features create conditions for precise detection of foreign substances due to a large detection area, fast optical and electronic response of the system, change of the conductivity even at small concentrations of surface functional groups and bioanalytes. Indeed, different authors reported on fabrication of biosensors using oxidized graphene to detect such VOCs of lung cancer as p-xylene [11], decane [12], hexanal, heptanal, undecane [5].

Despite GBM's advantages in detecting VOCs as lung cancer indicators, previous studies lack systematic results, hindering scientists' understanding of practical graphene-family nanomaterial implementation. Challenges remain: (i) lack of a standardized database for graphene-biomarker interactions and specific interaction fingerprints, (ii) unclear physical mechanisms for sensing polar and nonpolar lung cancer biomarkers, and (iii) low sensitivity to nonpolar VOCs. The differences in adsorption abilities of graphene to polar and nonpolar lung cancer biomarkers depending on solvent effect are never discussed, and a comprehensive DFT analysis on adsorption capacity of GBM to VOC biomarkers of lung cancer has not been carried out, yet. Considering the key issues mentioned, we explore ways to address these unexplored scientific questions.

Method

Gaussian 16 package is utilized to perform all DFT calculations of VOC adsorption on gra-

