



## The graphene-on-diamond structure with Ni-catalyzed under high temperature

Xiaolu Yuan<sup>a</sup>, Jinlong Liu<sup>a</sup>, Jiangwei Liu<sup>b</sup>, Junjun Wei<sup>a</sup>, Liangxian Chen<sup>a</sup>, Chengming Li<sup>a,\*</sup>

<sup>a</sup> University of Science and Technology Beijing, No. 30, Xueyuan Road, Haidian Distrct, Beijing 100083, China

<sup>b</sup> National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan

### ARTICLE INFO

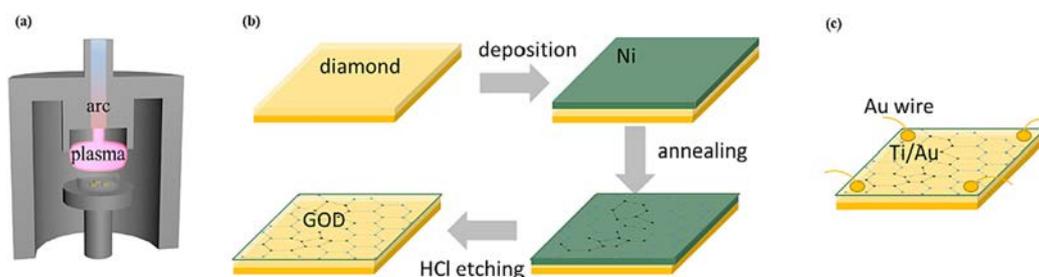
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### ABSTRACT

Graphene-on-diamond (GOD) composite structure has been attracting considerable attention due to the unique features for all carbon  $sp^3$ - $sp^2$  electronic applications. Whereby the electrical properties of diamond surface can be purposely tailored and significantly altered through transformed graphene layers. In this work, graphene-on-diamond composite structures were prepared by nickel-catalyzed high-temperature rapid annealing, and were analyzed by Raman, Hall effect measurement and Transmission electron microscopy (TEM). The results show that the difference in surface conductivity of graphene-on-diamond composite structure is mainly related to the number of transformed graphene layers, while the number of layers is mainly affected by annealing time and the thickness of nickel film. Hall measurement and TEM results show that when the transformed graphene becomes graphite with a lot of Ni atoms embedded into diamond, the surface carriers of graphene-on-diamond composite structure are electrons. On the contrary, when the transformed graphene is about 3 or 5 layers, the surface carriers are holes. These findings may provide a route for graphene-on-diamond structure to become a strong candidate for next generation complementary diamond electronic devices.

Video and Presentation to this article can be found online at <https://doi.org/10.1016/j.sctalk.2023.100277>.

### Figures and tables.



**Fig. 1.** Schematic diagram of GOD structure fabrication. (a) DC arc jet plasma equipment (b) Flow chart (c) Hall measurement using Van der Paw method.

\* Corresponding author.

E-mail address: [chengmli@mater.ustb.edu.cn](mailto:chengmli@mater.ustb.edu.cn) (C. Li).

**Table 1**

Hall measurements of GOD structure with different Ni thickness under 800 °C for 1.5 min.

Ni thickness (nm)	Sheet resistance ( $\Omega/\square$ )	Sheet concentration ( $\text{cm}^{-2}$ )	Hall mobility ( $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ )	Conductivity type
10	$\sim 10^8$	–	–	–
15	$\sim 10^4$	$\sim 10^{13}$	29	p
25	$\sim 10^4$	$\sim 10^{13}$	19	p
50	1.0	$\sim 10^{16}$	84	n
100	1.0	$\sim 10^{16}$	67	n

**Table 2**

Hall measurements of GOD structure under different annealing temperature with 40 nm Ni film for 1.5 min.

Temperature (°C)	Sheet resistance ( $\Omega/\square$ )	Sheet concentration ( $\text{cm}^{-2}$ )	Hall mobility ( $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ )	Conductivity type
800	$\sim 10^2$	$\sim 10^{14}$	114	p
900	$\sim 10^3$	$\sim 10^{14}$	15	n/p
1000	1.2	$\sim 10^{16}$	345	n

**Table 3**

Hall measurements of GOD structure under different annealing time with 40 nm Ni film at 800 °C.

Time (min)	Sheet resistance ( $\Omega/\square$ )	Sheet concentration ( $\text{cm}^{-2}$ )	Hall mobility ( $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ )	Conductivity type
1.0	$\sim 10^4$	$\sim 10^{12}$	37	p
1.5	$\sim 10^3$	$\sim 10^{13}$	33	p
2.0	$\sim 10^3$	$\sim 10^{12}$	53	p
2.5	$\sim 10^2$	$\sim 10^{14}$	55	p
3.0	$\sim 10^3$	$\sim 10^{13}$	82	p

**Table 4**

Hall measurements of GOD structure under different diamond substrate with 40 nm Ni film at 800 °C for 1.5 min.

Diamond substrate	Sheet resistance ( $\Omega/\square$ )	Sheet concentration ( $\text{cm}^{-2}$ )	Hall mobility ( $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ )	Conductivity type
HTHP Diamond	$\sim 10^4$	$\sim 10^{13}$	37	p
CVD Diamond	$\sim 10^4$	$\sim 10^{11}$	380	p
EPL Diamond	$\sim 10^4$	$\sim 10^{12}$	154	p

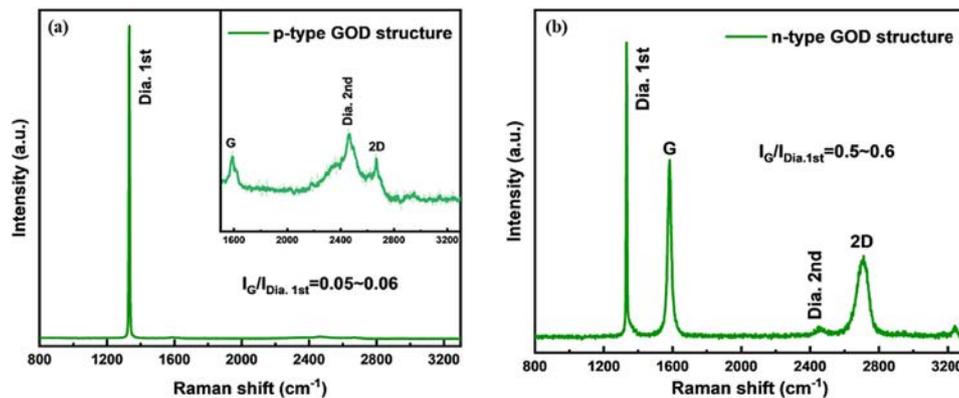


Fig. 2. Raman spectrum of GOD structure. (a) p-type (b) n-type.

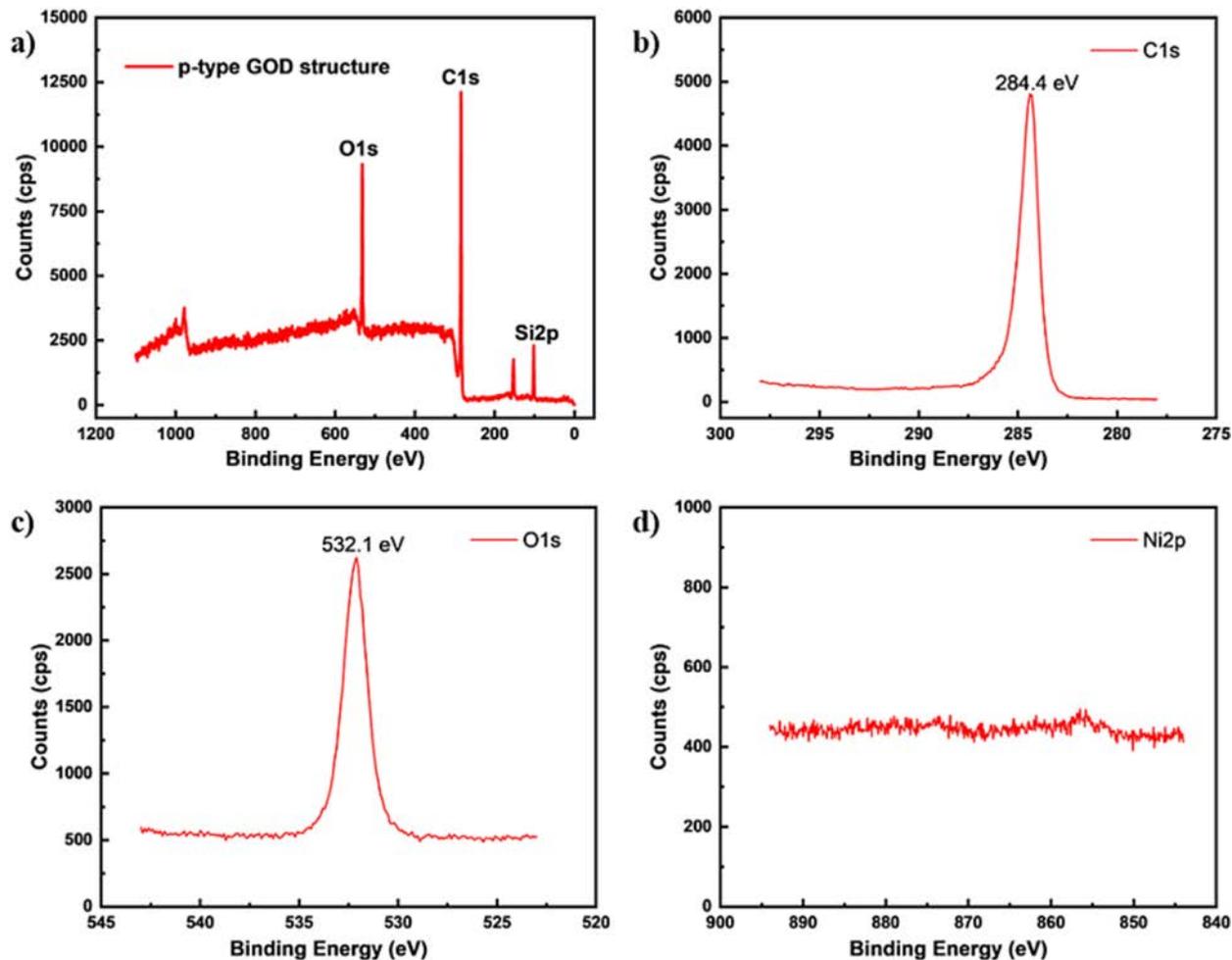


Fig. 3. XPS Spectrum of p-type GOD structure. (a) Survey (b) C1s (c) O1s (d) Ni2p.

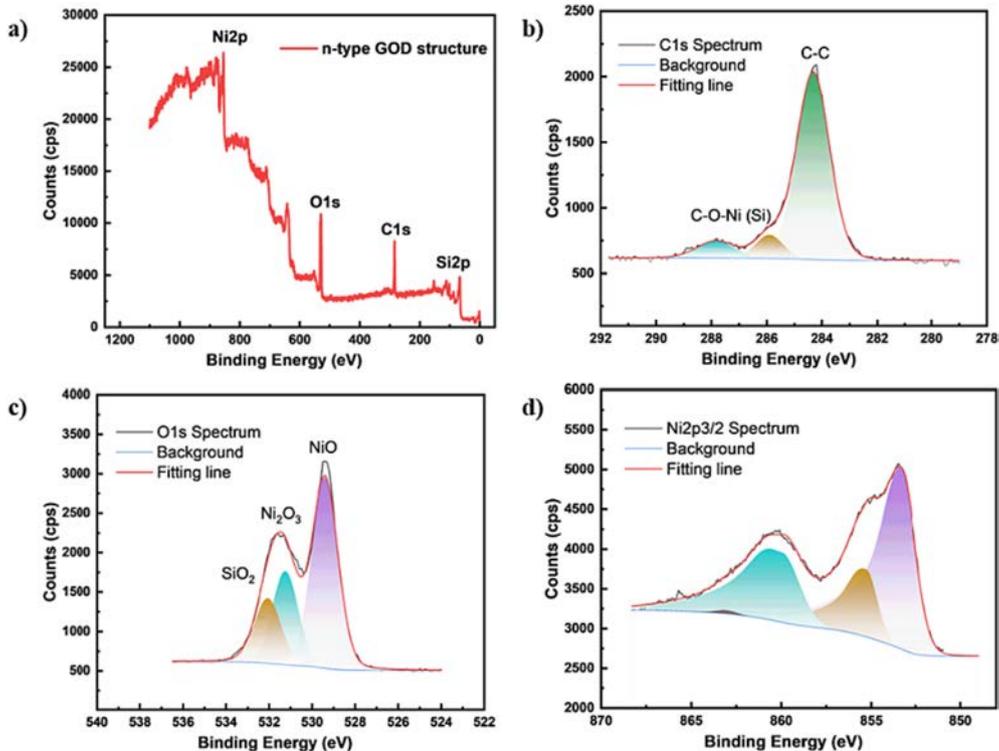


Fig. 4. XPS Spectrum of n-type GOD structure. (a) Survey (b) C1s (c) O1s (d) Ni2p<sub>3/2</sub>.

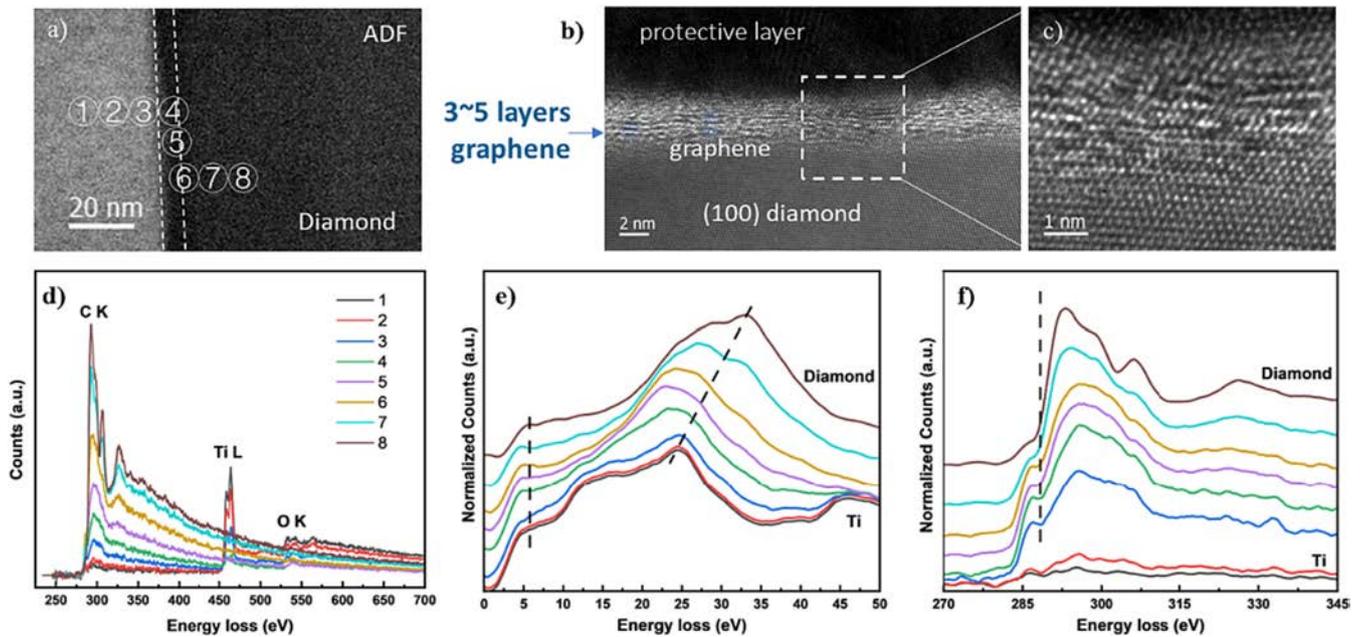


Fig. 5. TEM images and EELS spectra of p-type GOD structure. (a) ADF image for line scan (b) HRTEM image (c) Zoom-in area (d) EELS line scan spectrum (e) Low loss of C K edge (f) High loss of C K edge.

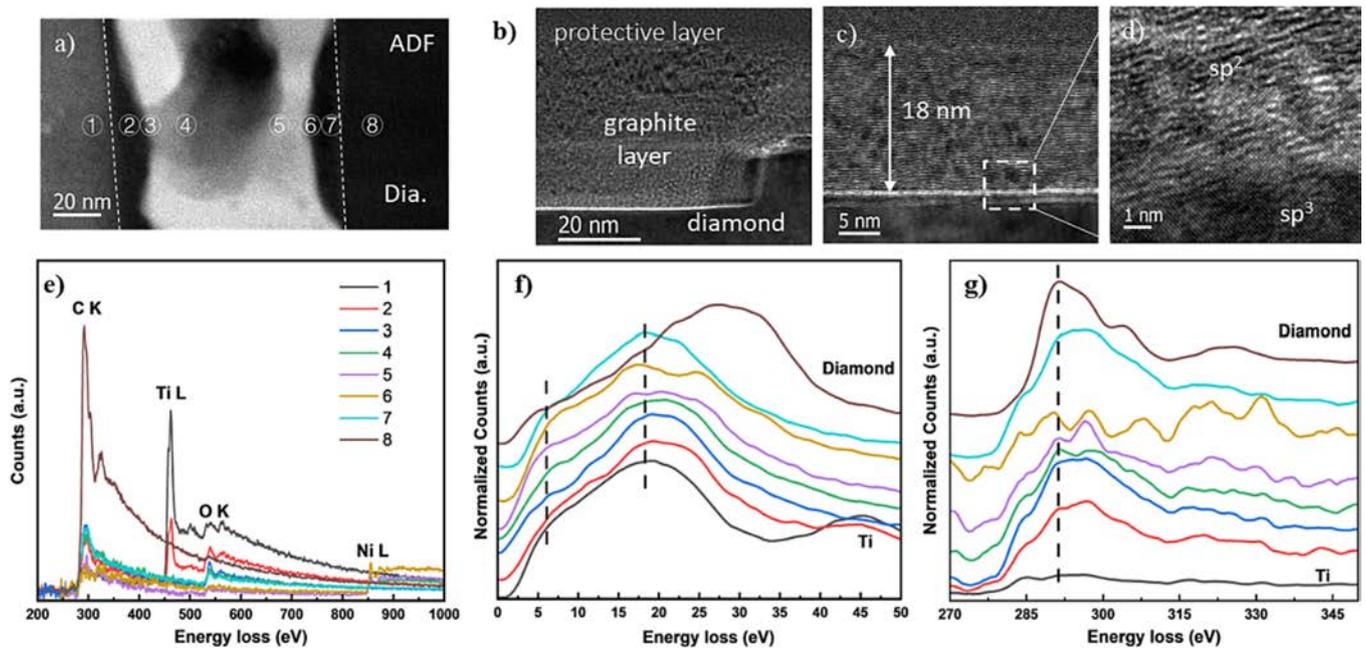


Fig. 6. TEM images and EELS spectra of n-type GOD structure. (a) ADF image for line scan (b) and (c) HRTEM images (d) Zoom-in area (e) EELS line scan spectrum (f) Low loss of C K edge (g) High loss of C K edge.

## CRedit authorship contribution statement

**Xiaolu Yuan:** Data curation, Writing – original draft. **Jinlong Liu:** Methodology. **Jiangwei Liu:** Visualization, Investigation. **Junjun Wei:** Supervision. **Liangxian Chen:** Validation. **Chengming Li:** Conceptualization.

## Data availability

Data will be made available on request.

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## Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Further reading

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**Xiaolu Yuan** received the B.S. degree in Inorganic Non-metallic Materials Engineering from Yanshan University, Qinhuangdao, China, in 2016. She is currently working toward the Ph.D. degree in Materials Science and Engineering with the Institute for Advanced Materials and Technology, University of Science and Technology Beijing, Beijing, China. Her research interests include the fabrication of diamond, graphene and diamond-based MOSFET.



**Jinlong Liu** was born in 1985, doctor of engineering, associate professor. He graduated from the Harbin Engineering University with a bachelor in 2007. In 2009, he received a master degree in materials science from Harbin Institute of Technology. In 2013, he got a doctor degree in materials science and engineering from Beijing University of Science and Technology. In 2014, he joined Institute of Advanced Materials and Technology, University of Science and Technology Beijing. His research now mainly focuses on the synthesis and application of carbon materials and other functional films. From 2017 to 2018, as a visiting scholar, he visited Argonne National Laboratory in USA, and worked on the diamond based electronic devices with 2-dimensional layer passivation. He has authored over 80 peer-reviewed carbon related publications and 20 authorized patents.

He has been awarded the Technical Invention of Ministry of Education of the People's Republic of China and Provincial Awards on Technology Advancement.



He has authored and co-authored over 70 Journal publications and three Japanese Patent.



**Dr. Junjun Wei**, is professor of Material Science at University of Science and Technology Beijing, China. He is the deputy director of the Functional Materials Research Institute, in Institute for Advanced Materials and Technology. He received his PhD degree from University of Science and Technology Beijing is 2009. In recent 5 years (2017–2022), as the principal investigator (PI), Professor Wei undertaken a number of national grade projects and enterprise projects. He has mainly engaged in the fabrication and application of large scale CVD diamond. He published more than 50 international academic papers, which are related to CVD diamond film, and obtained more than 10 authorized Chinese patents and several prizes in the recent 5 year (h-index: 15).



**Dr. Liangxian Chen** is a senior engineering from Institute of Advanced Materials and Technology, University of Science and Technology Beijing. He graduated from the Qingdao University of Science and Technology with a bachelor in 2005. In 2007 and 2013, he received the master degree and doctor degree in materials science and engineering from Beijing University of Science and Technology, respectively. He was a short-term visiting scholar at Texas A&M University in 2011. From 2013 to 2015, as a postdoctoral fellow, he worked in School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing. In 2015, he joined Institute of Advanced Materials and Technology, University of Science and Technology Beijing. His research now mainly focuses on the synthesis and application of diamond material and other functional films.



**Prof. Chengming Li** is now the director of Carbon-Based Materials and Functional Films Laboratory at University of Science and Technology Beijing (USTB). He has engaged in diamond material research for more than 30 years, and developed the DC arc-jet plasma technology for large-size, crack-free, ultrathick diamond plate deposition as well as microwave plasma technical equipment. His group firstly reported the electronic study of polycrystal & single crystal diamond in China. And their researches of the thermal application of diamond film are at the advanced level all around the world, which also promoted the industrial application of CVD free-standing diamond films.

Prof. Li has directed or was involved in more than 30 main projects, including the National Science and Technology Major Project (sub-project), National Key Research and Development Program of China, International Intergovernmental Cooperation Project (EU Horizon 2020), National “863” project, National Natural Science Foundation of China, etc. He is also currently served as the executive fellow of China Heat Treatment Association (CHTA), the fellow of the Pan-pacific International R&D and Industry Alliance of Single Crystal Diamond and Electronic Device, as well as the fellow of China Technical Committee for Standardization of Abrasive Engineering. At the same time, he has acted as associate editor of journals such as *Frontiers in Carbon*, *Functional Diamond*, and he also has joined the Editorial Board or Editor-in-Chief of special issue in several international journals. To date, he has authored over 300 peer-reviewed carbon related publications, 70 authorized patents, and participated in the compilation of 4 monographs.

He has been the recipient of various awards and recognitions. The research project of mass production of thermal-conductive diamond plate, which he mainly directed, has been successfully applied in the “BEIDOU” satellites and the “Long March-7” carrier rocket. This application milestone of the CVD diamond has been nominated by Ministry of Education of the People's Republic of China with the First-class of Technical Invention Award. Meanwhile, he has also awarded by 3 Ministerial or Provincial-level Awards on Technology Advancement.