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Progress in the graphene research since 2010

With exotic discovery of graphene, the focus of researchers brings initiatives in field of atom-thick two-dimensional (2D) materials having exceptional and extraordinary properties. In year 2010, Prof. Andre Geim and Prof. Konstantin Novoselov from the University of Manchester, UK were jointly awarded the Nobel Prize in Physics for their ground-breaking experiments on the two-dimensional material graphene. Data elucidated from Scopus (www.scopus.com) indicates that since 2010, on graphene 77,221 documents have been published from over 120 countries. Number of documents reported on graphene increased from 3,748 to 16,378 since 2010 to 2016. The graph depicts significant increase in the graphene research after 2010 (**Fig. 1a**).

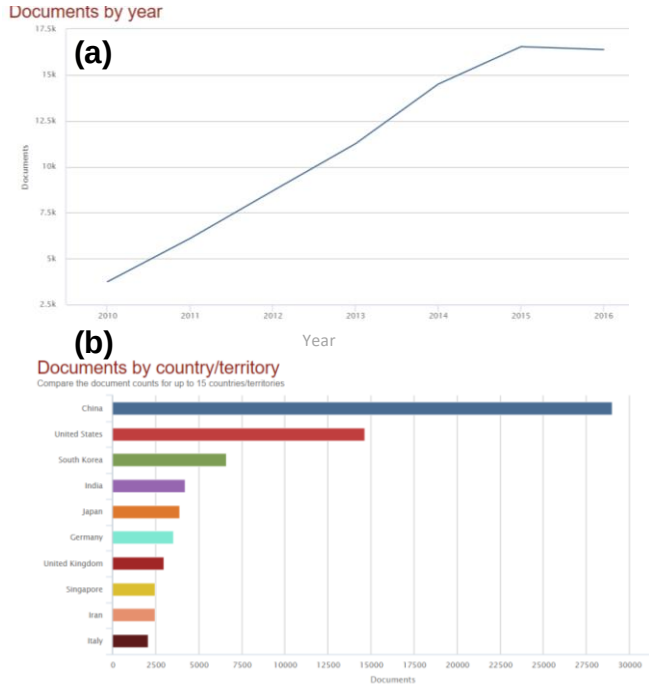

Fig 1. Distribution of (a) documents per year and (b) documents by country since 2010. The data were extracted as "Graphene" in all fields from Scopus (December 2016).

The most active countries are China, United States, South Korea, India, Japan, Germany, United Kingdom, Singapore, Iran and Italy ranked with respect to the documents reported during six years (**Fig. 1b**). Since 2010, 81.7% of the documents are reported as a research article and 51.5% of research is carried out in the field of material science (**Fig. 2**).

The dimensionality of material plays an important role in tuning different properties, depending on the arrangement of atoms in 0, 1, 2 and 3-dimensional crystal structure. 2D materials have atomically-thick geometry with intrinsic flexibility and can easily be integrated with various substrates because of absence of surface dangling bonds. The 2D crystals having unusual physical phenomenon tender a wide scope of new materials for potential applications such as super thin nanomaterials capable with a high degree of anisotropy and chemical functionality.

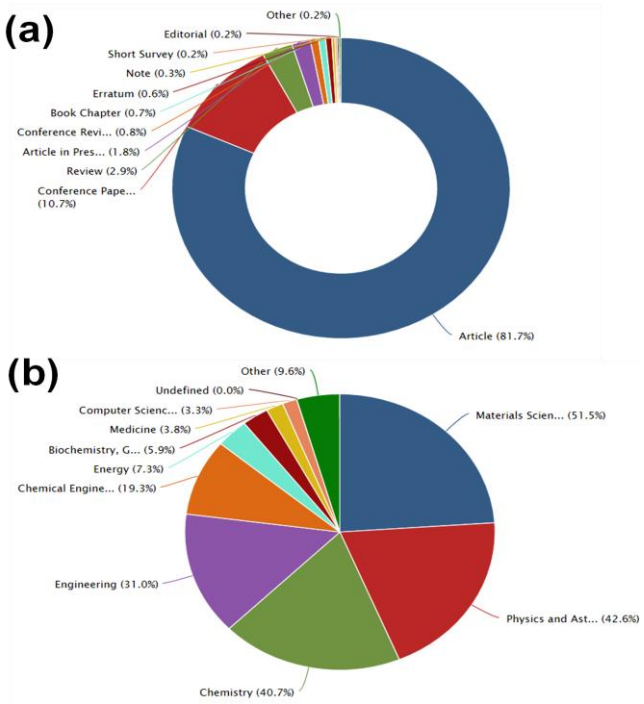

Fig. 2. Distribution of documents reported in graphene by (a) Type and (b) subject area since 2010. The data were extracted as "Graphene" in all fields from Scopus (December 2016).

Table 1. List of top-ten graphene researcher institutes/organisation and their world ranking based on the number of articles published*.

World ranking	Name of Organisation	Country	Number of documents published
1.	Chinese Academy of Sciences	China	1641
2.	Nanyang Technological University	Singapore	1346
3.	Tsinghua University	China	1318
4.	National University of Singapore	Singapore	983
5.	Sungkyunkwan University	South Korea	892
6.	Peking University	China	774
7.	Nanjing University	China	749
8.	Fudan University	China	715
9.	Zhejiang University	China	692
10.	University of Science and Technology of China	China	682

**The data were extracted as "Graphene" in all fields from Scopus (December 2016).*

Table 2. List of top-ten graphene researchers and their world ranking based on the number of articles published*.

World ranking	Name of Researcher	Affiliation	Number of documents published
1.	Martin Pumera	Nanyang Technological University, Division of Chemistry and Biological Chemistry, Singapore	225
2.	Rodney S. Ruoff	Ulsan National Institute of Science and Technology, Department of Chemistry, Ulsan, South Korea	207
3.	François Maria Peeters	Universiteit Antwerpen, Department of Physics, Antwerpen, Belgium	191
4.	Xinliang Feng	Technische Universitat Dresden, Department of Chemistry and Food Chemistry, Dresden, Germany	174
5.	Takashi Taniguchi	National Institute for Materials Science Tsukuba, Tsukuba, Japan	167
6.	Pulickel M.Ajayan	Rice University, Department of Materials Science and NanoEngineering, Houston, United States	165
7.	Kostya Kostya S. Novoselov	University of Manchester, School of Physics and Astronomy, Manchester, United Kingdom	164
8.	Taiichi Otsuji	Tohoku University, Research Institute of Electrical Communication, Sendai, Japan	160
9.	James M. Tour	Rice University, Department of Chemistry, Houston, United States	152
10.	Kläus Müllen	Max Planck Institute for Polymer Research, Mainz, Germany	140

**The data were extracted as "Graphene" in all fields from Scopus (December 2016).*

In ongoing research, graphene has a vast amount of interest in growing world, which is, a monolayer of carbon atoms tightly packed in 2D honeycomb lattice with sp^2 bonded carbon atoms with its unusual properties give rise to different applications. With exceptional properties, there are some shortcoming as pristine graphene [**1-16**]. Stacking of graphene layer are problematic due to π−π and hydrophobic interactions. Pristine graphene is zero band gap material and is insoluble in polar solvents and are hydrophobic naturally with poor catalytic performance. The interactions between graphene and smaller molecules are weak. Because of these above-mentioned limitations, possible application of graphene is restricted. The chemical modification and electronic structure modification cannot be controlled. So chemical functionalization is an operative methodology to alter the structure and many properties of graphene like chemical, mechanical and photosensitive properties and done by number of methods filtration, solvent supported techniques, layer by layer assembly. Due to zero band gap of graphene, its application in field of sensors and semiconductors like transistors and band gap tuning of graphene is carried out by many methods like doping and covalent and non-covalent functionalization of graphene.

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With best regards
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