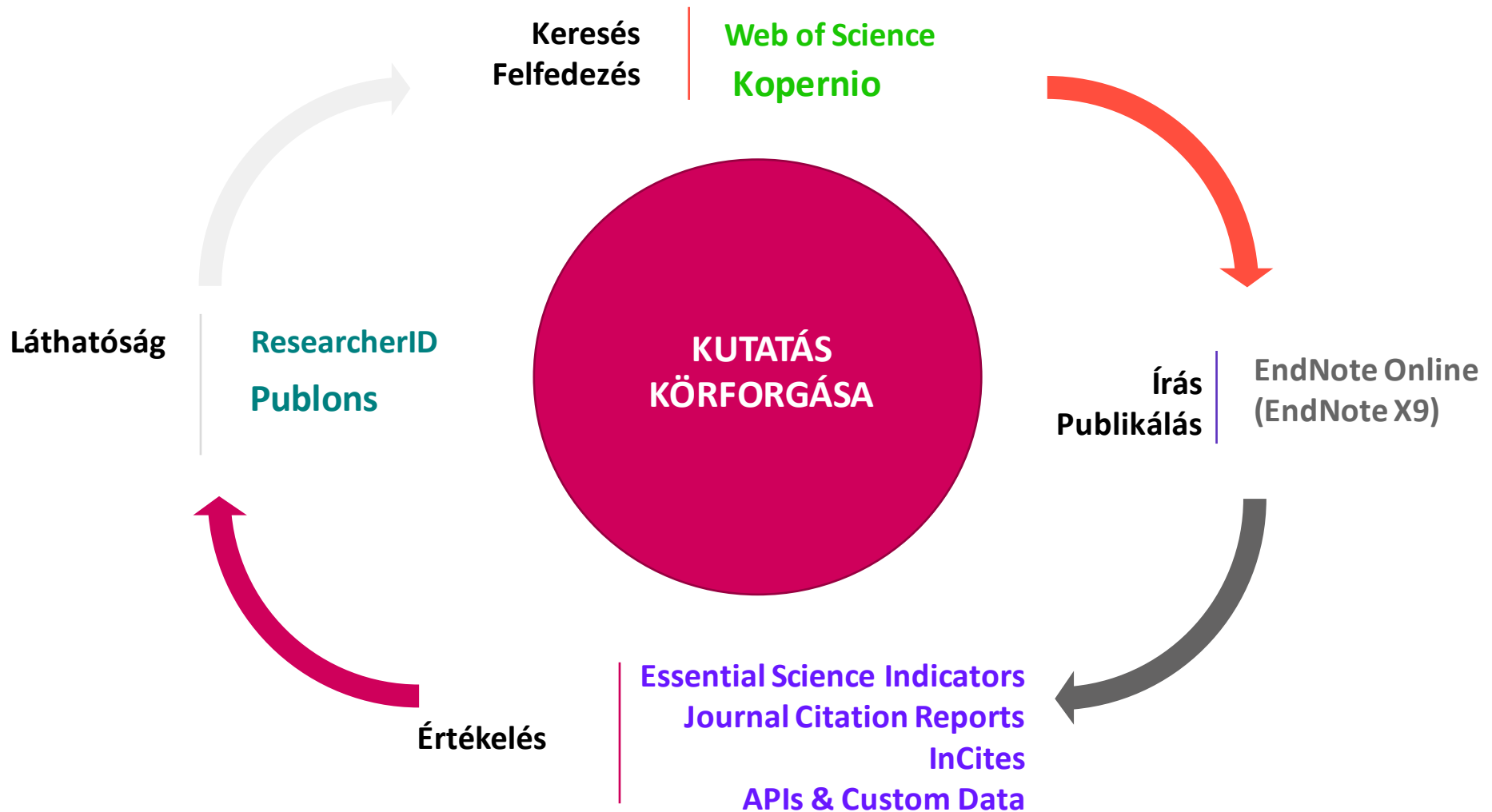


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Electric field effect in atomically thin carbon films

By: Novoselov, KS (Novoselov, KS); Geim, AK (Geim, AK); Morozov, SV (Morozov, SV); Jiang, D (Jiang, D); Zhang, Y (Zhang, Y); Dubonos, SV (Dubonos, SV); Grigorieva, IV (Grigorieva, IV); Firsov, AA (Firsov, AA)
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Volume: 306 Issue: 5096 Pages: 666-669
DOI: 10.1126/science.1102896
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Abstract
We describe monocrystalline graphitic films, which are a few atoms thick but are nonetheless stable under ambient conditions, metallic, and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conduction bands, and they exhibit a strong ambipolar electric field effect such that electrons and holes in concentrations up to 10^{13} per square centimeter and with room-temperature mobilities of similar to 10,000 square centimeters per volt-second can be induced by applying gate voltage.

Keywords
KeyWords Plus: GRAPHITE; NANOTUBES; GRAPHENE; DEVICES

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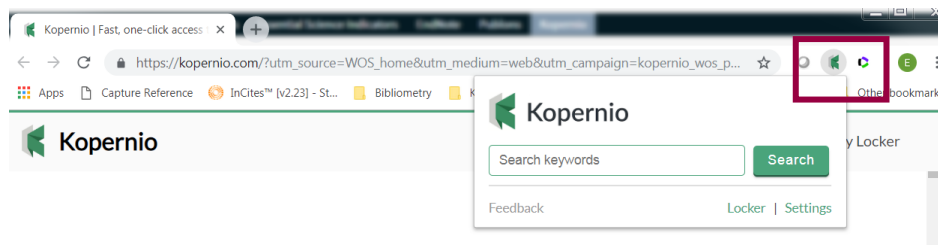
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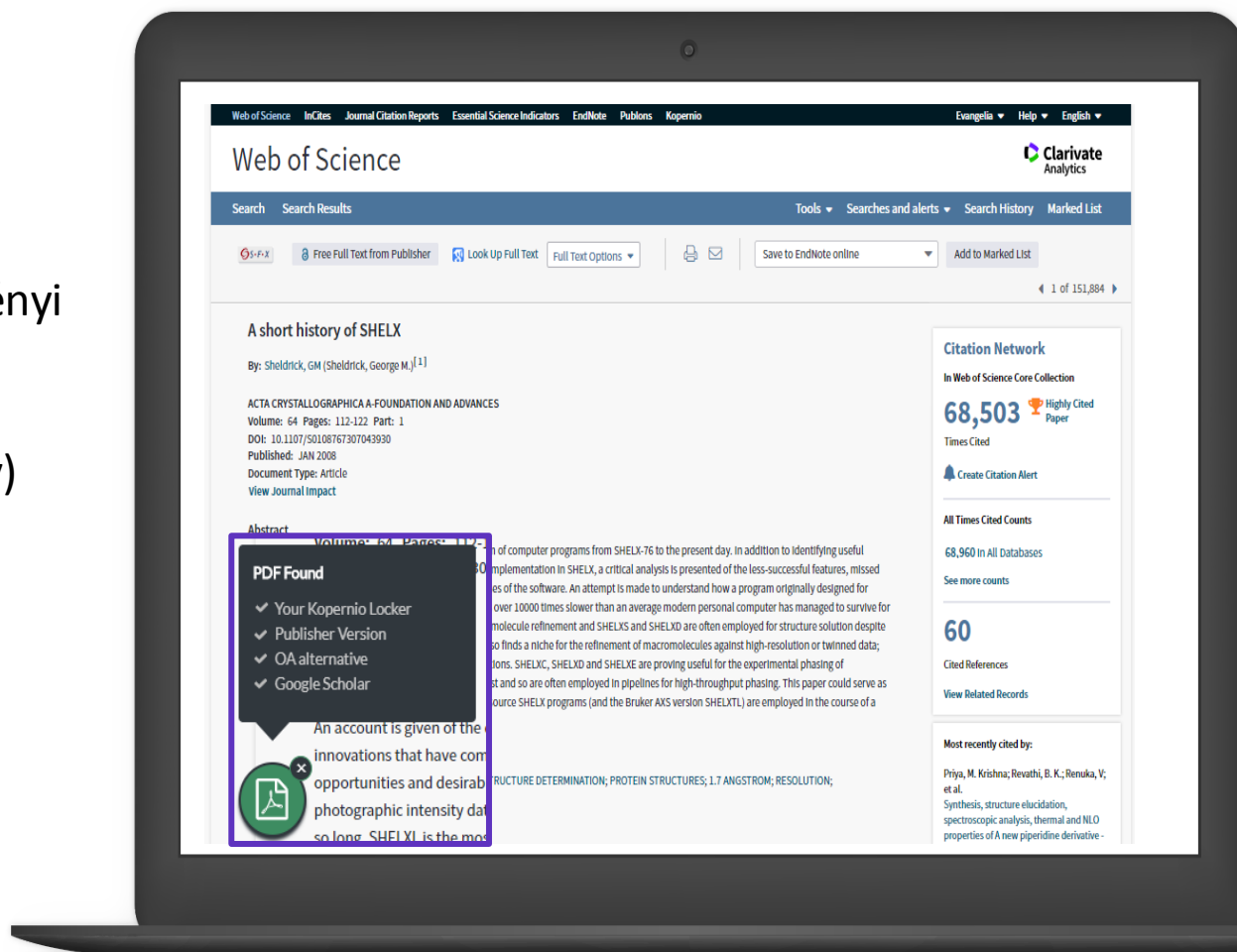


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Electric field effect in atomically thin carbon films

By: Novoselov, KS (Novoselov, KS); Geim, AK (Geim, AK); Morozov, SV (Morozov, SV); Jiang, D (Jiang, D); Zhang, Y (Zhang, Y); Dubonos, SV (Dubonos, SV); Grigorieva, IV (Grigorieva, IV); Firsov, AA (Firsov, AA)

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SCIENCE

Volume: 306 Issue: 5696 Pages: 666-669

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Abstract

We describe monocrystalline graphitic films, which are a few atoms thick but are nonetheless stable under ambient conditions, metallic, and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conduction bands, and they exhibit a strong ambipolar electric field effect such that electrons and holes in concentrations up to 10^{13} per square centimeter and with room-temperature mobilities of similar to 10,000 square centimeters per volt-second can be induced by applying gate voltage.

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K. S. Novoselov, *Science*(2004) %

Science Oct 22 (2004)

Electric Field Effect in Atomically Thin Carbon Films

K.S. Novoselov¹, A.K. Geim¹, S.V. Morozov², D. Jiang¹, Y. Zhang¹, S.V. Dubonos², I.V. Grigorieva¹, A.A. Firsov²

¹Department of Physics, University of Manchester, M13 9PL, Manchester, UK

²Institute for Microelectronics Technology, 142432 Chernogolovka, Russia

We describe monocrystalline graphitic films, which are just a few atoms thick but are nonetheless stable under ambient conditions, metallic and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conduction bands and to exhibit a strong ambipolar electric-field effect such that electrons and holes in concentrations up to 10^{13} cm^{-2} and with room-temperature mobilities $\sim 10,000 \text{ cm}^2/\text{Vs}$ can be induced by applying gate voltage.

One-sentence summary: We report a naturally-occurring two-dimensional material – graphene that can be viewed as a gigantic flat fullerene molecule, – describe its electronic properties and demonstrate all-metallic field-effect transistor, which uniquely exhibits ballistic transport at submicron distances even at room temperature.

The ability to control electronic properties of a material by externally applied voltage is at the heart of modern electronics. In many cases, it is the so-called electric field effect that allows one to vary the carrier concentration in a semiconductor device and, consequently, change an electric current through it. As the semiconductor industry is nearing the limits of performance improvements for the current technologies dominated by silicon, there is a constant search for new, non-traditional materials whose properties can be controlled by the electric field. The most notable examples of such materials developed recently are organic conductors [1] and carbon nanotubes [2]. It has long been particularly tempting to extend the use of the field effect to metals (e.g., to develop all-metallic transistors that could be scaled down to much smaller sizes and also have the potential to consume less energy and operate at higher frequencies than traditional semiconducting devices [3]). However, this would require atomically thin metal films because the electric field is screened at extremely short distances ($< 1 \text{ nm}$) and bulk carrier concentrations in metals are large compared to the surface charge that can be induced by the field effect. Films so thin are thermodynamically unstable and become discontinuous already at thicknesses of many nm; so far, this has proved to be an insurmountable obstacle to metallic electronics and no metal or semimetal has been shown to exhibit any



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...is a naturally occurring two-dimensional (2D) material that we call graphene (FLG) graphene is the name given to a single layer of carbon atoms densely packed into a benzene-like structure. This hypothetical material is widely used to describe properties of

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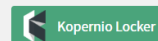
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K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, A. A. Firsov

Department of Physics, University of Manchester, M13 9PL, Manchester, UK

[†]Institute for Microelectronics Technology, 142452 Chernogolovka, Russia

We describe monocrystalline graphite films, which are just a few atoms thick but nonetheless stable under ambient conditions, metallic and of remarkably high quality. The films are found to be a two-dimensional semimetal with a zero overlap between valence and conduction bands and to exhibit a strong

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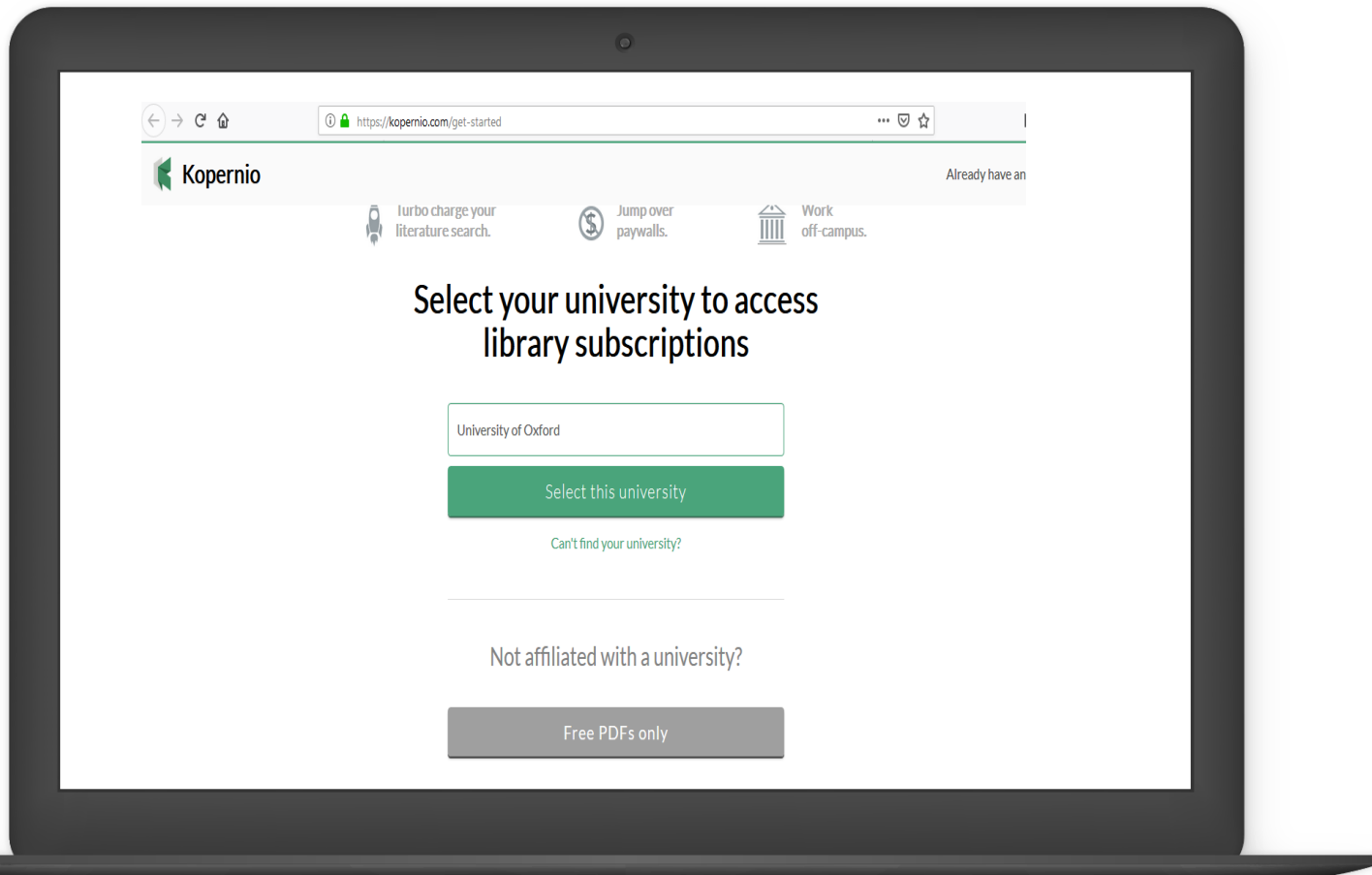
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John P. Perdew,¹ Adam Ruzsinszky,² Gábor I. Csók,³ Oleg A. Vydrov,⁴ Gustavo E. Scuseria,⁵ László A. Constantin,⁶ Xuebin Zhou,⁷ and Kieron Burke⁸

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[Cell](#). 2011 Mar 4;144(5):646-74. doi: 10.1016/j.cell.2011.02.013.

Hallmarks of cancer: the next generation.

[Hanahan D¹](#), [Weinberg RA](#).

⊕ Author information

Abstract

The hallmarks of cancer comprise six biological capabilities acquired during the multistep development of human tumors. The hallmarks constitute an organizing principle for rationalizing the complexities of neoplastic disease. They include sustaining proliferative signaling, evading growth suppressors, resisting cell death, enabling replicative immortality, inducing angiogenesis, and activating invasion and metastasis. Underlying these hallmarks are genome instability, which generates the genetic diversity that expedites their acquisition, and inflammation, which fosters multiple hallmark functions. Conceptual progress in the last decade has added two emerging hallmarks of potential generality to this list-reprogramming of energy metabolism and evading immune destruction. In addition to cancer cells, tumors exhibit another dimension of complexity: they contain a repertoire of recruited, ostensibly normal cells that contribute to the acquisition of hallmark traits by creating the "tumor environment." Recognition of the widespread applicability of these concepts will increasingly

development of new means to treat human cancer.

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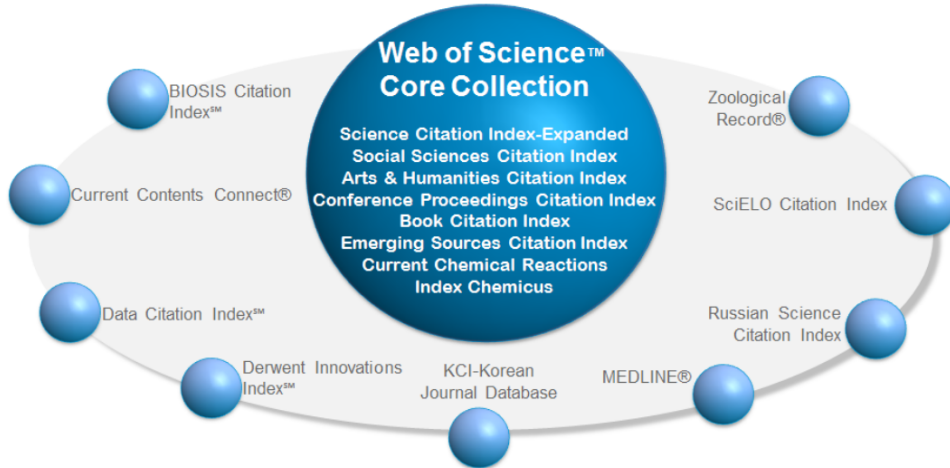
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