Dr Alexander A. Balandin
Distinguished Professor of Electrical and Computer Engineering,
University of California Riverside
USA

Office of the Chancellor
4108 Hinderaker Hall
900 University Avenue
Riverside, CA 92521

From: Kim A. Wilcox, Chancellor
University of California Riverside

To: World Cultural Council

Re: Nomination of Professor Alexander Balandin for the "Albert Einstein" World Award of Science

November 12, 2021

Dear Members of the World Cultural Council,

As Chancellor of the University of California Riverside, I am writing to nominate one of our outstanding scientists for the World Award of Science: Professor Alexander Balandin. By all measures, Prof. Balandin's pioneering discoveries in the area of nanotechnology, especially his work on low-dimensional materials like graphene, have revolutionized this area of scientific exploration and opened up new directions for research. (As one piece of evidence, I will point to over 57,000 citations to his publications.) Even more importantly, it also opened a broad spectrum of new practical applications, in products and technologies that affect everyday lives of people throughout the world. His discoveries already improved thermal management of electronic devices, are used in solar cells, and battery packs, and even in textiles. The impact of his work continues to grow and will contribute to improving efficiency, reducing energy consumption and our impact on the environment.

I should add that, in addition to being a pioneer in his scientific field, Prof. Balandin is a model scholar, who is also actively engaged in service for his research community and university, and in educating the next generation of scientist and engineers.

In the nomination package you will find details regarding Prof. Balandin's research accomplishments and its impacts that have led me to asses Prof. Balandin as one of the world's truly outstanding and impactful scientists.

Sincerely,

Kim A. Wilcox
Chancellor
University of California Riverside

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The University of Manchester

Faculty of Engineering and
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The University of Manchester
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To World Cultural Council

16 November 2021

RE: ***Letter of support for Prof. A. Balandin***

Dear Sir or Madam:

This letter is to support the nomination of Prof. Alexander Balandin for the *Albert Einstein World Award of Science*.

I followed Prof. Balandin's work since 2008, when I attended several of his invited talks at the international conferences in the field of graphene, and discussed science with him at many professional meetings. Over the years, Prof. Balandin demonstrated genuine research creativity, deep knowledge of several different research fields, and track record of discoveries and innovations. In the following, I describe in some details a few examples of Prof. Balandin's innovative research and out-of-box thinking, which allowed me to refer to him as an ideal candidate for your award.

In 2004 – 2008, after the first exfoliation of graphene and initial electrical transport measurements, the attention of the international research community was focused on electronic properties of graphene. Prof. Balandin went to an entirely different direction. He conducted pioneering studies of phonon transport and thermal properties of graphene. He experimentally discovered that the intrinsic thermal conductivity of graphene can be exceptionally high and, in principle, exceed that of basal planes of bulk graphite – an absolutely non-trivial conclusion. His trailblazing Nano Letter (2008) paper on thermal conductivity of graphene created a whole new research area in the field graphene. He followed up with a series of papers, both experimental and theoretical, where he showed that the two-dimensional nature of graphene reveals itself not only in electronic but also in phononic properties.

In order to measure the thermal conductivity of graphene, Prof. Balandin came up with an unconventional use of Raman spectroscopy, essentially converting a Raman spectrometer into a heater and a thermometer. This innovative Raman optothermal method has been adopted in many laboratories, and used for investigation of thermal properties of a wide range of 2D materials. In 2012, Prof. Balandin published a pioneering paper on the use of graphene in thermal interface materials. This work expanded the graphene thermal field into the direction of applied research with numerous thermal management applications, including thermal pastes and thermal coatings. Graphene thermal applications have now found their way to the commercial products. Prof. Balandin remained at the vanguard the graphene thermal field, leading its development in both fundamental science and practical application directions.

Dr. K. S. Novoselov
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Condensed Matter Group, School of Physics & Astronomy
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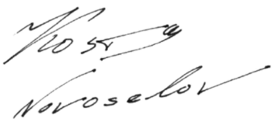
Prof. Balandin's contributions to the field of graphene and 2D materials are not limited to the phonon transport alone. In line with his characteristic approach of coming up with new ideas and research directions, he went on to study low-frequency current fluctuations in graphene, *i.e.* 1/f noise. He made seminal contributions in this area as well, publishing the first experimental reports that reveal the mechanism of 1/f noise in graphene and explained its difference from electronic noise in semiconductors and conventional metals. In an interesting and unexpected way, Prof. Balandin demonstrated that the noise in graphene can be turned into a signal and used to identify analyte without any surface functionalization. His Nature Nano (2013) paper became a standard reference source for information on noise in graphene devices. The 1/f noise research is important for sensor applications of graphene and other 2D materials.

In the decade after 2010, a lot of attention of the graphene and 2D materials community was directed to 2D van der Waals materials of the transition metal dichalcogenide (TMD) group. Most of the researchers were attempting to find 2D materials with a suitable band gap and a high mobility to replicate the action of the conventional field-effect transistor. Prof. Balandin, again, demonstrated creativity and innovation by focusing on 2D TMD materials with the charge-density-wave properties. In 2012, he reported a possibility of controlling the phase transition temperature in 2D TMD van der Waals materials by changing their thickness. In 2016, he demonstrated the first charge-density-wave device operating at room temperature. His Nature Nano (2016) paper, where a new device functionality was achieved with the intrinsic properties of three different 2D materials, was an important landmark in the 2D materials field. It helped in the rebirth of the charge-density-wave field, expanding it to 2D materials, and demonstrated the pathway for the charge-density-wave devices to practical applications.

To summarize, Prof. Balandin has made exceptional research contributions in broad research areas, ranging from nanofabrication and electronic transport to Raman spectroscopy and thermal transport. I am confident that he is an ideal candidate for the *Albert Einstein World Award of Science* by the World Cultural Council.

Sincerely yours

K. S. Novoselov



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To summarize, Prof. Balandin has made exceptional research contributions in broad research areas, ranging from nanofabrication and electronic transport to Raman spectroscopy and thermal transport. I am confident that he is an ideal candidate for the *Albert Einstein World Award of Science* by the World Cultural Council.

Sincerely yours

K. S. Novoselov

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Rensselaer

MICHAEL S. SHUR, DR. SC.
PATRICIA W. AND C. SHELDON ROBERTS PROFESSOR
ECSE and PHYSICS, APPLIED PHYSICS, AND ASTRONOMY

November 12, 2021

World Cultural Council

Re.: Nomination of Prof. Alexander Balandin for the Albert Einstein World Award of Science

Dear Colleagues,

I would like to offer my strongest support to the nomination of Professor Alexander Balandin for the Albert Einstein World Award of Science of the World Cultural Council.

I have been following Alexander's research publications for more than 20 years. I had a few chances to meet him at conferences and coauthored several technical journal papers and one chapter on the noise reduction approaches in transistors. I am absolutely confident that Alexander is the right choice for this award.

Alexander is one of the brightest researchers I have met over my long academic and entrepreneurial career. He is the one who is constantly able to generate new ideas, pursue them in the lab, and implement them in practice. His wide educational background allows him to start with the innovative physical concept, synthesize the materials, nanofabricate prototype devices, and test them. He goes all the way from fundamental physics to engineering applications.

Alexander is an internationally recognized leader in nanoscience, electronics, phononics, and quantum materials research. His expertise covers a broad range of nanotechnology, materials science, electronics, photonics, phononics, and spintronics fields. He is widely regarded as a pioneer of the graphene thermal field who discovered experimentally and explained theoretically unique heat conduction properties of graphene and investigated graphene technologies for thermal management. His numerous research achievements include development of the phonon engineering approaches for nanoscale devices, electronic noise reduction in wide-band-gap-semiconductor electronics, the first demonstration of the charge-density-wave electronic devices operating at room temperature, and the proposals of many other innovative devices.

Alexander's academic standing is evident from major awards he received such as The MRS Medal from the Materials Research Society, The Vannevar Bush Faculty Fellow award from the U.S. government, The Brillouin Medal from the International Phononics Society, and the Pioneer of Nanotechnology Award from the IEEE Nanotechnology Council. His research is interdisciplinary; and he excelled in every element of it as seen from his numerous keynote talks at top international conferences and elections to Fellow status in many professional societies, including MRS, APS, IEEE, OSA, SPIE, IOP, IOM3 and AAAS. He has been among the Clarivate Analytics and Thomson Reuters Highly Cited Researchers in the Physics and Cross-Discipline categories for several years.

Alexander's creativity is exceptional. It may originate from this fundamental education, which include both theory and experiment, and passion for research. One day he can go to a Physics Department and give a

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condensed-matter talk like a hard-core physicist. On another day, he can deliver an applied research talk at an Engineering Department or industry laboratory in a way easily understood by the engineering practitioners. The innovative ideas he generated span a wide range, from fundamental physics concepts to engineering solutions for specific problems.

In 1999, he came up with the idea of investigating the effects of the acoustic phonon confinement in nanostructures on the thermal conductivity of such structures. Nobody before him thought about it – everybody was studying the reduction in heat conduction owing to phonon – boundary scattering only. He pursued this direction theoretically and computationally for a decade, and after that built a Brillouin spectrometer and demonstrated it experimentally (Nature Com., 7, 13400 (2016)). In 2010 – 2015 period, while others were studying low-frequency noise in 2D materials in order to reduce it, he experimentally demonstrated the use of noise as a sensing signal in graphene and MoS2 devices (Nano Lett., 12, 2294 (2012)), and then utilized noise measurements as spectroscopy of phase transitions in 2D charge-density-wave materials (Nano Letters, 18, 3630 (2018)). The list of such examples is too long to reproduce here.

Education of the future technology experts is a part of the professor's mission. Alexander performs this function exceptionally well. It is hard to find a better research supervisor and mentor than him. He graduated more than 37 PhDs who are advancing technology in such industry leaders as Apple, Intel, and Micron, to name a few. He is a champion of promoting diversity – among his PhD graduates, many are women and members of the underrepresented minorities in science and engineering – Hispanics and African Americans. His PhD students received various awards at professional conferences and project report workshops. Four of his PhD students received awards at the Best Doctoral Dissertation Competitions organized by the Society of Woman Engineers (SWE). Several of his students received awards at the Materials Research Society (MRS) Spring meetings. These are all indicators of exciting research and excellent mentorship.

Finally, concluding this letter, I would like to state that Professor Balandin is the best candidate for the prestigious Albert Einstein World Award of Science of the World Cultural Council.

Thank you.

Sincerely,

/Michael Shur/

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Date: November 12, 2021

To: World Cultural Council

From: Chris Lynch
Dean, Bourns College of Engineering
William R. Johnson, Jr. Family Chair

RE: **Rationale for the nomination of Prof. Alexander Balandin for the "Albert Einstein World Award of Science"**

The advances in nanoscience, since its advent in early 2000's, have changed our understanding of matter and ushered technologies that were unthinkable a few decades ago. Nanomaterials can already be found in a variety of industrial and consumer products, in areas ranging from electronics to healthcare and environmental protection, and in the near future they will become ubiquitous, contributing to improved quality of life of today's world population.

Professor Balandin is one of the pioneers of the technological revolution that made these advances possible. His best-known contribution to the field of nanotechnology is the discovery of the thermal properties of graphene, that laid the foundation of the graphene thermal field. After the first exfoliation of graphene by Novoselov and Geim (Nobel Prize in Physics, 2010), when the international research community focussed on electronic properties of graphene, Professor Balandin had the foresight to study, instead, its thermal conduction. His Nano Letter (2008) paper, that reported uniquely high thermal conductivity of graphene is now cited more than 13200 times. Following this experimental discovery, he studied fundamental aspects of thermal transport in graphene, explaining the physical reasons for the thermal conductivity of graphene being higher than that of basal planes of bulk graphite (Nature Materials (2010 and 2011)). Then, together with his PhD students, he synthesized the first thermal interface materials (TIMs) with graphene and few-layer graphene, and, importantly, demonstrated the use of graphene in thermal technologies for heat removal. To these days, the graphene thermal field continues its rapid growth, both in fundamental science and engineering. Professor Balandin's achievements in this field have been recognized by the scientific community via The IEEE Pioneer of Nanotechnology Award, The MRS Medal, and The Brillouin Medal.

Professor Balandin's research of thermal properties of graphene and other van der Waals materials has led to development of commercial thermal management technologies, including TIMs and thermal phase change materials (PCM) with graphene/FLG fillers. Commercial TIMs and PCMs with graphene are now utilized for heat removal in electronics, battery packs and solar cells. The thermal properties of graphene are essential in composite substrates, heat-spreading coatings, and even textiles. All these applications are rooted in Professor Balandin's research on heat conduction in graphene.

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Other scientific contributions of Professor Balandin in the area of nanoscience include the following:

- The invention of the Raman optothermal method for measuring thermal conductivity of graphene and two-dimensional (2D) materials, that has become conventional and adopted in laboratories worldwide.
- Demonstration of the first room-temperature charge-density-wave (CDW) quantum devices based on 2D van der Waals materials such as 1T-TaS_2 (Nature Nano (2016)). This development stimulated interest in practical applications of quantum materials.
- Discovery of the exceptional current carrying capacity of one-dimensional (1D) van der Waals materials such as $TaSe_3$. This discovery became instrumental in Professor Balandin's receving the Vannevar Bush Faculty Fellowship from the U.S. government with the $3M funding for research of 1D quantum materials.
- Synthesis of the first composites with 1D van der Waals metal fillers, and their application in electromagnetic (EM) interference shielding (Advanced Materials (2021)). Electromagnetic shielding is important for protecting humans and environment from excess EM radiation emanating from cell phones and other electromagnetic devices.
- Explanation of the electronic noise mechanism in various technologically important materials, and development of an innovative characterization technique based on low-frequency noise measurements.

Professor Balandin is not only an outstanding scientist — he is also an active member of his research community and dedicated educator. He has graduated 37 PhD students who are already making their own contributions to science and technology, working for hi-tech companies, government laboratories, and academia. Among his lasting achievements in the area of engineering education is the creation of the Materials Science and Engineering program at UC Riverside, for which he served as the Founding Chair. This now thriving program is providing undergraduate and graduate education in all areas of materials science, including nanotechnology. These contributions to engineering education further amplify Professor Balandin's impact on the field of nanotechnology.

Additional information about Professor Balandin's record can be found in the submitted materials, including his CV, publications, and reference letters, that include one letter from a Nobel Prize laureate Professor K. S. Novoselov.

In conclusion, Professor Balandin's eminent status as a pioneer in the field of nanotechnology, profound impact of his work on emerging technologies, and wide range of applications of his research that will contribute to improving lives of today's and future generations, make him uniquely eligible for the "Albert Einstein World Award of Science".

ALEXANDER A. BALANDIN

Distinguished Professor of Electrical and Computer Engineering
University of California Presidential Chair Professor of Materials Science and Engineering
Director, Phonon Optimized Engineered Materials (POEM) Center
University of California, Riverside, California 92521 USA
E-mail: balandin@ece.ucr.edu Web: https://balandingroup.ucr.edu/

EDUCATION

- B.S. in Mathematics, Moscow Institute of Physics and Technology, Russia, 1989
- M.S. in Applied Physics, Moscow Institute of Physics and Technology, Russia, 1991
- Ph.D. in Electrical Engineering, University of Notre Dame, USA, 1996
- Postdoctoral Research, University of California, Los Angeles, USA, 1997 – 1999

EMPLOYMENT HISTORY

- Distinguished Professor (2016 – present), Department of Electrical and Computer Engineering, University of California, Riverside, USA
- Director (2017 – 2020), Interim Director (2016 – 2017), UCR Nanofabrication Facility, University of California, Riverside, USA
- University of California Presidential Chair Professor (2013 – present), University of California, USA
- Director (2013 – present), Phonon Optimized Engineered Materials (POEM) Center, University of California, Riverside, USA
- Founding Chair (2006 – 2011), Materials Science and Engineering Program, University of California, Riverside, USA
- Visiting Professor (2005 – 2006), Department of Engineering, University of Cambridge, UK
- Professor (2005 – 2016), Associate Professor (2001 – 2005), Assistant Professor (1999 – 2001), Department of Electrical and Computer Engineering, University of California, Riverside, USA
- Research Engineer (1997 – 1999), Electrical Engineering Department, University of California**,** Los Angeles, USA
- Research Assistant (1991 – 1993), Moscow Institute of Physics and Technology (MIPT) and the Russian Space Agency, Dolgoprudny, Moscow Region, Russia

AWARDS AND RECOGNITIONS

- The Vannevar Bush Faculty Fellowship (VBFF) with $3,000,000.00 research funding for the project "One-Dimensional Quantum Materials", 2021 – present
- The Brillouin Medal – International Phononics Society (IPS), 2019
  "For discovery of unique phonon properties of graphene, and contributions to the development of graphene thermal management applications."
- Clarivate Analytics (Thomson Reuters) Highly Cited Researcher, 2015 – present (each year)
- Fellow of MRS – The Materials Research Society, 2014
- The MRS Medal – The Materials Research Society, 2013
  "For discovery of the extraordinary high intrinsic thermal conductivity of graphene, development of an original optothermal measurement technique for investigation of thermal properties of graphene, and theoretical explanation of the unique features of the phonon transport in graphene"
- Fellow of IEEE – The Institute of Electrical and Electronics Engineering, 2013
- Fellow of APS – The American Physical Society, 2012
- Fellow of IOM3 – The Institute of Materials, Minerals and Mining, U.K., 2012

- Fellow of IOP – The Institute of Physics, U.K., 2012
- The Pioneer of Nanotechnology Award – IEEE, 2011
  "For pioneering contributions to nanoscale phonon transport with applications in nanodevices, graphene devices, thermoelectric and thermal management of advanced electronics."
- Fellow of SPIE - The International Society for Optical Engineering, 2011
- Fellow of OSA - The Optical Society of America, 2011
- Semiconductor Research Corporation (SRC) Inventor Award, USA, 2009, 2010
- Fellow of AAAS - The American Association for Advancement of Science, 2007
- Distinguished Lecturer, CNRS, Pierre and Marie Curie Institute, Paris, France, 2005
- Visiting Fellow, Pembroke College, University of Cambridge, UK, 2005
- Office of Naval Research (ONR) Young Investigator Award, Arlington, USA, 2002
- National Science Foundation (NSF) Faculty CAREER Award, 2001
- University of California Regents Faculty Award, USA, 2000
- US Civil Research and Development Foundation (CRDF) Award, Arlington, USA, 1999
- Merrill Lynch Innovative Engineering Research Award, WTC, New York, USA, 1998
- Elected Member, *Eta Kappa Nu* Engineering Honor Society, Notre Dame, USA, 1994
- *Summa Cum Laude*, Moscow Institute of Physics and Technology, Russia, 1991

JOURNAL EDITOR AND ADVISORY SERVICE

- Deputy Editor-in-Chief, Applied Physics Letters, 2016 – present
- Member of the Board of Advisors, Advanced Electronic Materials, 2016 – present
- Member of the Board of Advisors, Journal of Carbon Research, 2016 – present
- Senior Editor, IEEE Transactions on Nanotechnology, 2013 – 2015

PUBLICATION RECORD

Web of Science Publons (https://publons.com/researcher/4062951/alexander-balandin/) tracks 314 of my published works. I have been designated as a Clarivate Analytics (formerly Thomson Reuters) Highly Cited Researcher every year since 2015. This designation recognizers "the true pioneers in their fields over the last decade, demonstrated by the production of multiple highly-cited papers that rank in the top 1% by citations for field and year in the Web of Science. Of the world's scientists, Clarivate™ Highly Cited Researchers truly are one in 1,000." My h-index is 95, with the total number of citations above 57,000 (2021). My papers are cited more than 5,000 times per year. My citation record is entirely due to my own creative research work together with my PhD students during my tenure as a professor at UC Riverside. For a complete list of publications, visit my research group's web-site at https://balandingroup.ucr.edu/ or Google Scholar: https://scholar.google.com/ .

SELECTED INTERNATIONAL PLENARY AND KEYNOTE CONFERENCE TALKS

- Keynote Talk, "Quasi 2D and 1D van der Waals quantum materials," Low-Dimensional Materials and Devices Conference, SPIE Optics + Photonics, San Diego, USA, 2021
- Keynote Talk, "Two-dimensional charge-density-wave quantum materials," Graphene and 2DM Online Conference: Fundamental Research Insights, Madrid, Spain, 2021
- Keynote Talk "Electronic properties and device applications of quasi-2D charge density wave materials," Symposium – 2D Atomic and Molecular Sheets, Materials Research Society (MRS) Fall Meeting, 2020
- Plenary Lecture, "Low-frequency noise in low-dimensional van der Waals materials: The charge-density-wave effects, unusual Lorentzian and more," 5th International Conference on Noise and Fluctuations (ICNF), Neuchâtel, Switzerland, 2019

- Plenary Lecture, "Phonons and thermal transport in graphene," The 5th International Conference on Phononic Crystals, Metamaterials, Phonon Transport, and Topological Phononics (Phononics 2019), Tucson, Arizona, USA, 2019 – *The Brillouin Medal Talk*
- Plenary Lecture, "Phonons in graphene and van der Waals materials" Materials Research Society (MRS) Fall Meeting, Boston, USA, 2013 – *The MRS Medal Talk*
- Keynote Conference Opening Talk, "Phononics in low-dimensional materials," International CECAM Workshop Nanophononics, University of Bremen, Germany, 2013
- Keynote Lecture, "Phonon engineering: From nanowires and quantum dots to graphene and topological insulators," ICREA Workshop on Phonon Engineering, St Feliux de Guixol, Barcelona, Spain, 2010
- Keynote Lecture, "Thermal conductivity of graphene and carbon materials," International Workshop on Nanocarbon Photonics and Optoelectronics, North Karelia, Finland, 2010
- Plenary Lecture, "Nanoscale phonon engineering," International Conference on Phonon Scattering in Condensed Matter Physics – The 11th PHONONS Conference, St. Petersburg, Russia, 2004
- Plenary Lecture, "Investigation of low-frequency noise in heterostructure field-effect transistors based on wide band gap semiconductors," The 16th International Conference on Noise in Physical Systems and 1/*f* Fluctuations (ICNF), Gainesville, Florida, USA, 2001

RESEARCH IMPACT

- The phonon engineering approaches that I developed are incorporated in design of modern thermoelectric devices for increasing the efficiency of energy conversion; in electronic devices for enhancement of the electron mobility and improvement of heat removal; in photonic devices for tuning the light – matter interactions. All these advancements contribute to energy saving and improves renewable energy generation.
- Graphene thermal technologies have become the large-scale practical applications of graphene – one can now buy commercial thermal paste or epoxies with graphene fillers, or even sport jackets with graphene-enhanced textile for better heat spreading.
- Several methods of the electronic noise reduction that I developed are used in modern semiconductor electronic. The noise spectroscopy has become an established technique, which provides information about electronic properties of materials. Noise reduction is important for energy saving.
- The quasi-1D quantum materials are now considered for possible applications as interconnects and the multi-functional composites. Composites with quasi-1D materials demonstrated potential for electromagnetic interference (EMI) shielding, important for protecting humans from electromagnetic radiation, and improving quality of communications while reducing energy consumption.

CONTRIBUTIONS TO EQUITY, DIVERSITY AND INCLUSION

More than 1/3rd of my engineering PhD graduates are women (37 total graduates). Fifteen PhD graduates are members of the minority groups underrepresented in science and engineering. My research group is one of the most diverse in the science and engineering fields in the University of California.

REFERENCES

Professor Konstantin Novoselov (Nobel Prize Laureate, 2010)
University of Manchester
E-mail: kostya@manchester.ac.uk

Distinguished Professor Michael Shur
Rensselaer Polytechnic Institute
Email: shurm@rpi.edu

Papers – A list of 10 Important Publications

Chronological Order

1) A. Balandin and K. L. Wang, "Significant decrease of the lattice thermal conductivity due to phonon confinement in a free-standing semiconductor quantum well," Phys. Rev. B, 58, 1544 (1998).

2) A. A. Balandin, S. Ghosh, W. Bao, I. Calizo, D. Teweldebrhan, F. Miao, and C. N. Lau, "Superior thermal conductivity of single-layer graphene," Nano Lett., 8, 902 (2008) – cited 13342 times.

3) S. Ghosh, W. Bao, D. L. Nika, S. Subrina, E. P. Pokatilov, C. N. Lau, and A. A. Balandin, "Dimensional crossover of thermal transport in few-layer graphene," Nature Mater., 9, 555 (2010).

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5) K. M. F. Shahil and A. A. Balandin, "Graphene-multilayer graphene nanocomposites as highly efficient thermal interface materials," Nano Lett., 12, 861 (2012).

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