Guo *et al. eLight* (2026) 6:20
https://doi.org/10.1186/s43593-026-00138-9
elight.springeropen.com

EDITORIAL

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Nobel Laureate conversation: Konstantin Novoselov

Chenzi Guo[1*], Ying He[2*], Tianfu Li[2*], Yufei Ma[2*] and Yongkang Dong[2*]

1 Editorial

Professor Konstantin Novoselov shared the 2010 Nobel Prize in Physics with Prof. Andrei Geim for groundbreaking experiments on the two-dimensional material graphene. His pioneering mechanical exfoliation technique unlocked the entire field of van der Waals materials, while his sustained research spans twistronics, moiré superlattices, AI-assisted materials design, functional intelligent materials and optoelectronic van der Waals devices. Balancing fundamental quantum physics research with industrial translation, he also maintains a unique personal intersection of scientific research and artistic creation. In this *eLight* conversation, we revisit the origin of graphene, discuss the core bottlenecks and future trends of 2D materials, explore the paradigm shift brought by artificial intelligence to materials discovery, and capture his insight on academic life, and advice for young researchers.

2 Conversation

Q1: Back in 2004, Prof. Andrei Geim and you isolated monolayer graphene via mechanical exfoliation—a discovery that was surprising and transformative. Could you walk us through the story behind this breakthrough, and share any unexpected experimental observations from the early stage?

A1: The whole discovery grew out of our lab's signature "Friday evening experiments"—tradition established by Andre Geim which let us explore ideas outside our mainstream research directions. Andrei thought it would be fun to make graphite-based transistors, which required ultra-thin graphite films. He purchased expensive graphite and assigned a PhD student to polish it down to thin sheets. After a week of work, unfortunately, the student only produced graphite dust and asked for more graphite, so we temporarily shelved the project, thinking it was not feasible.

At the same time, we were building a scanning tunneling microscope (STM) in the lab, and graphite is a standard calibration sample for STMs because it can be cleaved to produce clean surfaces. Scotch tape was commonly used to obtain freshly-cleaved graphite surfaces prior to measurement, and when handling this Scotch tape, it suddenly occurs to me that the tape might be the solution to getting thin sheets. On a whim, we tried peeling graphite with adhesive tape—and within half an hour, we fabricated our first few thin graphitic devices, then we started to work on that. This kind of accidental breakthrough emerge only from sustained experimentation and continuous exploration of related material systems.

Q2: Before your work, the condensed matter physics community widely held the consensus that free-standing single-layer 2D atomic crystals could not remain stable under ambient conditions. You gradually thinned graphite down to monolayer graphene through repeated trials. Could you recall how you

*Correspondence:
Chenzi Guo
guocz@ciomp.ac.cn
Ying He
yinghe@hit.edu.cn
Tianfu Li
litf@hit.edu.cn
Yufei Ma
mayufei@hit.edu.cn
Yongkang Dong
dongyk@hit.edu.cn
[1] Light Publishing Group, Changchun, China
[2] Harbin Institute of Technology, Harbin, China

systematically verified the thermodynamic stability of graphene step by step?

A2: We spent nearly 1 year progressing from early experiments towards actual graphene. At the very beginning, the only knowledge about graphene we had that it should not exist. But along the way, we studied quantum transport and electrostatic gating effects that drew us deeper into the topic, until we finally isolated genuine monolayer graphene. The stable existence of this single-layer crystal was a massive shock to our initial understanding.

The critical evidence came from two numbered devices, K50 (monolayer graphene) and K51 (bilayer graphene). The two samples exhibited drastically different quantum transport signatures—their electronic behaviors were fundamentally distinct. The only physically consistent explanation for such divergent quantum responses was that one contained a single atomic layer and the other two stacked layers. We were fortunate to obtain both samples simultaneously, which gave us direct comparative experimental proof. Even so, it took extensive repeated measurements and control experiments to rule out sample contamination, substrate interference and other artifacts before we fully confirmed monolayer graphene's ambient stability.

Q3: Thanks to your foundational work, the van der Waals material library has expanded enormously far beyond graphene and traditional transition metal dichalcogenides (TMDs). Which emerging categories of 2D materials do you believe will become dominant research trends in the coming years, driven by their unique optical and electronic properties relevant to photonics?

A3: The field has branched into countless subdirections, and for a journal like *eLight* focused on optics and photonics, optically active 2D semiconductors are particularly promising. This includes light-emitting van der Waals crystals (including 2D ferromagnetic materials), each with tunable bandgaps and distinct optical parameters, but also anisotropic materials for waveguide and photonic applications, etc.

One standout feature of these new materials is their strong in-plane and out-of-plane anisotropy, delivering optical responses unavailable in conventional bulk semiconductors. An even more powerful research direction is artificial van der Waals heterostructures: if no natural material satisfies your target functionality, you can stack dissimilar atomic layers from scratch to engineer custom artificial materials with tailored optoelectronic performance. This bottom-up heterostructure design will continue to generate transformative optical devices for decades to come.

Q4: You have been a prominent advocate for integrating artificial intelligence into materials discovery and functional design in recent years. How will AI reshape and challenge the traditional paradigm for identifying and engineering new functional 2D materials?

A4: We are still far from unlocking AI's full potential for materials science. Conventional first-principles calculations struggle to predict dynamic, metastable functional materials that actively alter their properties under external stimuli—these complex behaviors were long considered computationally intractable, so few research groups attempted theoretical modeling for them. AI is poised to fill this gap, though its practical implementation is far from straightforward.

Early overhyped expectations assumed generic large language models or simple prompt-based AI could instantly output material synthesis recipes, yet widespread trials yielded limited tangible progress. The field has since sobered up: we must create AI platforms purpose-built for physical materials systems, rather than relying on general text-oriented LLMs. Our group is constructing domain-specific AI frameworks embedded with complete synthesis pathway knowledge, which can navigate material databases and optimize experimental fabrication parameters natively—something generic AI cannot achieve.

Initial enthusiasm faded after disappointing preliminary results, but many teams globally are now advancing targeted AI-materials platforms. I remain optimistic that this cross-disciplinary tool will revolutionize our discovery pipeline over the next decade.

Q5: Twistronics and moiré superlattices have grown into a core mainstream subfield of 2D materials, especially for exploring strongly correlated quantum states. What major unresolved fundamental puzzles and computational bottlenecks currently hinder progress in this area?

A5: Moiré superlattices grant exceptional control over electronic band structures, allowing precise tuning of transport and optical properties—we can even modify the topological character of electronic bands by adjusting twist angles and stacking order. The primary obstacle lies in computational complexity. Complex moiré unit cells often contain hundreds, even thousands of atoms, rendering standard first-principles computational methods infeasible due to extreme computational cost.

We can qualitatively interpret most experimental phenomena observed in twisted heterostructures, but quantitative predictive modeling remains nearly impossible. The subtle atomic reconstruction within moiré domains further complicates calculations. At present, a universal theoretical or computational framework to reliably predict the quantum properties of arbitrary moiré superlattices does not exist, and this gap represents the biggest open challenge for twistronics research.

Q6: Your research group actively advances both fundamental research and industrial technology translation. How do you balance these two priorities?

A6: Fundamentally, we pursue scientific research because it brings intellectual excitement and curiosity-driven joy. Industrial projects are not a secondary obligation—we only engage with industrial collaborations that offer unconventional, thought-provoking research angles that align with our core interests.

We could expand industrial partnerships far more widely, but human time is limited to 24 h each day, so we must carefully select projects that genuinely intrigue us. Many translational projects require spinning out startup companies, which demands students and researchers with specialized entrepreneurial talent, and such skilled team members are not always easy to recruit. Basic research always retains priority in our group, while industrial work proceeds selectively alongside it as a complementary branch of exploration.

Q7: After decades of 2D materials research, what core bottleneck stands in the way of large-scale commercialization of 2D material-based products? If you had to name the top three "killer applications" that will drive mass industrial adoption, what would they be?

A7: There is no major technical barrier holding back commercialization; the technology advances at its own natural pace, and new 2D-material-enabled products launch monthly. The biggest hidden obstacle is industry-wide knowledge gaps: manufacturing engineers and industrial technologists lack systematic training on processing, integrating and embedding atomically thin van der Waals materials into existing supply chains and standard fabrication workflows. Synthesizing high-quality flakes is only the first step; seamless integration into mature industrial production lines remains a steep learning curve for manufacturers.

For high-impact killer applications aligned with photonics and optoelectronics, silicon photonic modulators built from 2D materials stand out as the most transformative upcoming product. Beyond optical modulators, flexible optoelectronic sensors and high-performance energy storage electrodes will also become major mass-market commercial applications in the medium term.

Q8: What guidance would you offer to young researchers pursuing research career?

A8: Young researchers should follow their genuine personal curiosity in science above all else. If your passion lies in chemistry, pursue chemistry; if you thrive in theoretical physics, dive into physics. You may even choose to launch startups focused on optical or graphene-related technologies—this field still holds endless room for original discovery, and no single research direction is saturated. Do not restrict yourself to established hot topics simply because senior scientists or mainstream publications highlight them. Independent, curiosity-driven exploration is the most reliable path to groundbreaking original work.

Q9: You are widely known to maintain a deep passion for painting alongside scientific research. How do you reconcile your dual interests in art and physics, and which pursuit ultimately holds your core emotional passion?

A9: I have seriously considered abandoning scientific research to work as a full-time artist. Artistic creation is incredibly tempting, and I could financially sustain myself through painting. However, after thorough reflection, I realized I would retain an overwhelming scientific curiosity and feel compelled to return to laboratory research. Emotionally, I cannot find full satisfaction through art alone; scientific exploration fulfills my core intellectual drive in a way painting cannot replace. Art remains a vital complementary hobby that broadens my thinking, yet physics stays my central lifelong passion.

Q10: *eLight* aims to break traditional disciplinary boundaries and lead cross-cutting research bridging optics, materials science and nanotechnology. As a pioneer at the intersection of these fields, what suggestions would you give to the journal to advance its cross-disciplinary mission?

A10: The most exciting modern scientific breakthroughs consistently emerge at the boundaries between traditional disciplines, and the intersection of optics, nanotechnology and van der Waals materials generates an extraordinary volume of novel, unforeseen phenomena. I firmly believe the most impactful new discoveries in photonics will originate from these interdisciplinary interfaces. I encourage *eLight* to keep prioritizing cross-field submissions, support collaborative work between physicists, materials scientists and optical engineers, and highlight research that merges novel low-dimensional materials with photonic device design—this is where the future of the field lies.

Q11: You received the Nobel Prize in Physics at a relatively young age. What were the most profound positive and challenging changes to your academic and personal life after winning the prize?

A11: I was extremely fortunate to receive immediate, wise advice from my mentor, collaborator and friend Professor Andrei Geim on the day the Nobel announcement was released: avoid letting the award alter your core research identity and daily routine. I followed this guidance strictly. I never reference the Nobel Prize in my academic talks, and I only present post-2010 research results in lectures, never the graphene discovery work that earned the award.

For the first five years after receiving the prize, I deliberately kept my daily lab schedule unchanged to avoid losing focus on experimental work. This strategy was successful; I quickly returned to my original research rhythm, which protected the continuity of my scientific output. The main downside is the constant stream of public speaking, media and administrative obligations that fragment research time. Overall, the biggest lesson is separating the symbolic honor of the prize from your ongoing scientific work—recognition does not replace consistent, hands-on experimental exploration.

Q12: What's the biggest failure you encountered throughout your research career?

A12: I've encountered quite a few setbacks along the way. As an undergraduate, I started an architecture business and almost dropped out of school. During my PhD, I quit twice before finally completing it on the third attempt. I'm the kind of person who never asks for permission when I want to do something. Perhaps that's why, when most people believed that free-standing single-layer 2D atomic crystals are not achievable, but I was still willing to try at any expenses. Sometimes, progress comes from questioning what everyone else takes for granted, this can possibly lead to failures, but could also possibly open the door to breakthroughs that others never thought about.

Q13: Looking into the future 5–10 years, what's your research blueprint?

A13: Scientific progress does not operate according to rigid pre-written blueprints. We set moderately ambitious core long-term goals—our primary focus over the next decade is investigating metastable functional van der Waals materials. However, we always hope our defined targets will be disrupted by far more interesting unplanned experimental findings along the way. Unexpected emergent phenomena in the lab consistently redirect our research trajectory, and those serendipitous detours usually yield the most transformative results. We maintain flexible project structures to pivot quickly toward surprising new physics uncovered during experiments.

Published online: 09 July 2026