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Evidence for Graphene Formation in Thomas Edison's 1879 Carbon Filament Experiments

Lucas Eddy, Chi Hun Choi, Justin Sharp, Carter Kittrell, Yimo Han, and James M. Tour*

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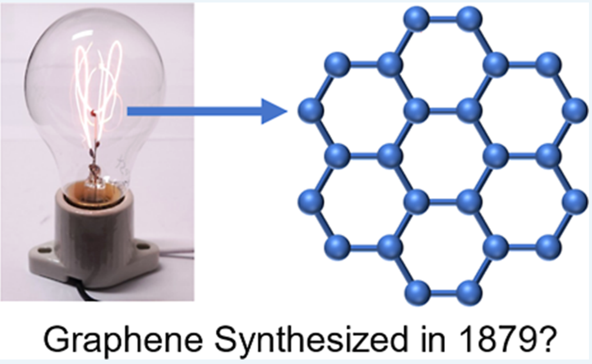
ABSTRACT: Thomas Alva Edison was an American inventor famous for his breakthroughs in stable electric lighting. He founded one of the first modern research laboratories in Menlo Park, New Jersey, United States and invented the first commercially viable electric lightbulb in 1879. Here, we recreated conditions similar to those used by Edison to produce his original carbon filament light bulb and show that the carbon filament was converted into graphene. This suggests that Edison might have indeed formed the same in his experiments 145 years ago.



KEYWORDS: *graphene, Joule heating, Thomas Edison, light bulb, turbostratic, 2-dimensional*

1. INTRODUCTION

As a principal investigator, Edison led a team of researchers that produced ~400 patents from the New Jersey facility.[1] In 1879, Edison announced the invention of a stable light bulb, which was patented in 1880.[2] This light bulb could be heated to 1800 to 2300 °C and exhibited a lifetime of up to 1200 h,[3,4] far beyond that achieved by any previous light bulb. When Edison turned on one of his carbon filament lightbulbs, originally sourced from pyrolyzed cotton thread or pyrolyzed Japanese bamboo, he imposed 110 V across the 100 to 500 Ω filament,[2] thus rapidly Joule heating it to >1800 °C. In doing so, Edison may have synthesized a turbostratically stacked 2D material.

Graphene is a 2D allotrope of graphite that was first reportedly characterized in 1964 by Boehm[5] and was later isolated by mechanical exfoliation and electrically characterized in 2004 by Konstantin Novoselov and Andre Geim.[6] The latter two received the Nobel Prize in Physics in 2010 for this and other groundbreaking works on graphene. Many others have also contributed to our current understanding of graphene and its synthesis methods. Benjamin Collins Brodie in 1859 developed a method for oxidizing graphite that would later become one of the pathways for producing graphene oxide,[7] and his contribution is discussed further in Supporting Note 1. The Acheson process, submitted for a patent in 1893 by Edward Goodrich Acheson, provided an efficient method for converting carbon materials into graphite.[8] Later in 1948, few-layer graphite, now called few-layer graphene, was examined by transmission electron microscopy (TEM) by Ruess and Vogt.[9]

Since 2010, graphene has attracted interest in fundamental and applied sciences for its extraordinary mechanical and electrical properties. These properties include its use as a zero band gap semiconductor,[6] its ability to support massless Dirac Fermions,[10] its high elastic modulus of 1 TPa,[11] and its high electron mobility of 2.5×10^5 cm^2 V^{-1} s^{-1} (ref 11) in its single-layer form. Graphene also exists in other morphologies, including multilayer graphene[12−14] and turbostratic (inter-layer-disordered) graphene.[15−17] Flash Joule heating (FJH) has recently emerged as a rapid and scalable technique for producing turbostratic graphene.[18−20] This method involves applying a voltage across a resistive medium, especially a carbon feedstock, to rapidly Joule heat the medium to ~2000 to 3000 °C, thereby converting the feedstock into graphene.

2. REPRODUCING THE EDISON LIGHT BULB EXPERIMENT

Reproducing conditions similar to those used by Thomas Edison (Figure 1A,B) in the late 1800s, our present findings indicate that Edison might have synthesized turbostratic graphene 145 years ago during his light bulb experiments. This would have occurred through the FJH process. To

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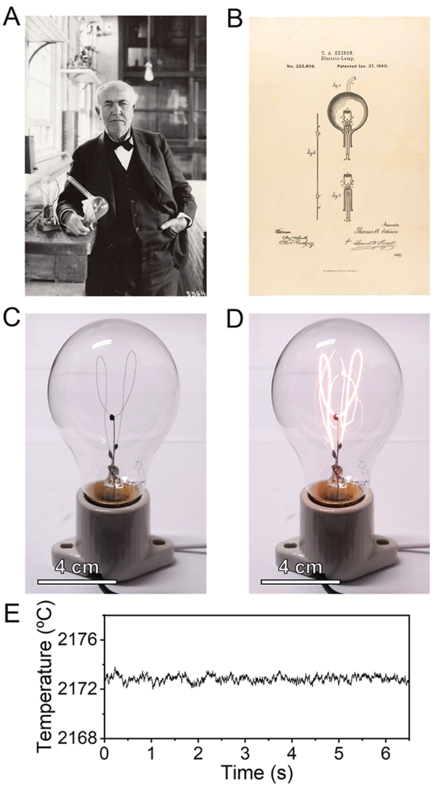

Figure 1. Thomas Edison's light bulb. (A) Image of Thomas Edison holding one of his many light bulb prototypes provided by the U.S. National Park Service via Wikimedia Commons, ref 21 1919. (B) Schematic drawing of the carbon filament light bulb in Thomas Edison's patent provided by the National Archives (records of the Patent and Trademark Office, record group 241, National Archives Identifier 595450), reference 2, 1880. (C) Photograph of a carbon filament light bulb in the off state. (D) Photograph of the same light bulb with 110 V DC applied. (**E**) This voltage was applied to the filament until its temperature stabilized to 2173 °C. More discussion on temperature is contained in Supporting Note 2.

recreate Edison's conditions when heating his first carbon filament light bulbs, we obtained light bulbs similar to those he used[2] (Figure 1 and Table 1). This is a light bulb with a carbon filament that is ~170 μm in diameter (Figure S1) with an initial filament resistance of 353 Ω inside a vacuum-sealed bulb (Figure 1C). To replicate the heating conditions that Edison used, the light bulb was connected to a programmable power supply and the carbon filament was subjected to 110 V DC (Figure 1D) for only 20 s.

Table 1. Comparison of Parameters of Our Light Bulb and the Edison-like Light Bulb Reported in His U.S. Patent No. 223.898[2]

parameter	Edison patent light bulb	our light bulb
voltage	110 V	110 V
atmosphere	vacuum	vacuum
material	pyrolyzed Japanese bamboo	pyrolyzed Japanese bamboo
initial filament resistance	100−500 Ω	353 Ω
filament diameter	0.007 in. (178 μm)	172 μm

The electrical resistance of the filament was 234 Ω after it was cooled to room temperature. This 35% decrease in electrical resistance indicates a phase change in the filament. Additional filament parameters are listed in Table 2.

Table 2. Additional Critical Light Bulb Parameters[a]

parameter	value
before flash filament resistance	353 Ω
after flash filament resistance	234 Ω
filament length	16.44 cm
before flash filament diameter	172 μm
after flash filament diameter	170 μm
before flash filament cross-sectional area	2.32×10^{-8} m^2
after flash filament cross-sectional area	2.27×10^{-8} m^2
before flash filament surface area	8.89×10^{-5} m^2
after flash filament surface area	8.78×10^{-5} m^2
before flash filament volume	3.82×10^{-9} m^3
after flash filament volume	3.73×10^{-9} m^3
before flash filament resistivity	4980 μΩ·cm
after flash filament resistivity	3230 μΩ·cm

[a] The resistance, length, and diameter values were measured. The values following these were calculated from these first four. No length change was measurable before and after the flash reaction. The precise location along the fiber for the measurements before and after could not be attained.

The light bulb was then cut open to remove the carbon filament for characterization (Figure S2). Optical microscopic images illustrate a color change of the carbon filament from dark gray to lustrous silver (Figure 2).

3. SPECTROSCOPIC AND MICROSCOPIC EVIDENCE

Raman spectroscopy characterization was employed on the carbon filament before and after being subjected to 110 V for 20 s. Raman spectroscopy analysis is one of the primary tools used to characterize carbon compounds, especially graphene.[15,18,22,23] The positions and relative intensities of graphene's three most prominent Raman peaks, namely, the D, G, and 2D peaks, are used to identify graphene and distinguish it from graphite and amorphous carbon. The D Raman peak at (~1350 cm^{-1}, at 532 nm excitation) arises from defects in the graphene lattice, the G peak (~1585 cm^{-1}) occurs from the presence of sp^2-carbon bonds,[24] and the 2D (G′) peak (~2700 cm^{-1}) is correlated with graphene crystallinity. Thus, the D/G peak ratio ($I_{D/G}$) is used to quantify defects present in the carbon lattice, while the 2D/G peak ratio ($I_{2D/G}$) is used as a metric of graphene quality. Conventionally, an $I_{2D/G}$ of at least 0.3 is necessary to suggest graphene synthesis.[25−27] Less prominent Raman peaks, namely, the M peak (~1750 cm^{-1}) and turbostratic (TS) peaks of TS$_1$ (~1886 cm^{-1}) and TS$_2$ (~2035 cm^{-1}), can also be used to further distinguish between ordered (AB- or ABC-stacked) and turbostratic graphene.

Figure 3A shows the Raman spectrum of the raw carbon filament. The small and broad 2D peak indicates short-range ordering typical of combusted or pyrolyzed carbon products.[25] The $I_{2D/G}$ is only 0.21 and is characteristic of an amorphous carbon. After being heated at 110 V for 20 s, the Raman spectrum of the carbon filament exhibits a decrease in the $I_{D/G}$ ratio and an increase in the $I_{2D/G}$ ratio to 0.70, well above the 0.3 threshold, indicating both a reduction in defect density and an increase in crystalline ordering consistent with graphene formation.[18] Furthermore, the 2D peak can be fitted with a single Lorentzian peak, a positive indicator of turbostratic

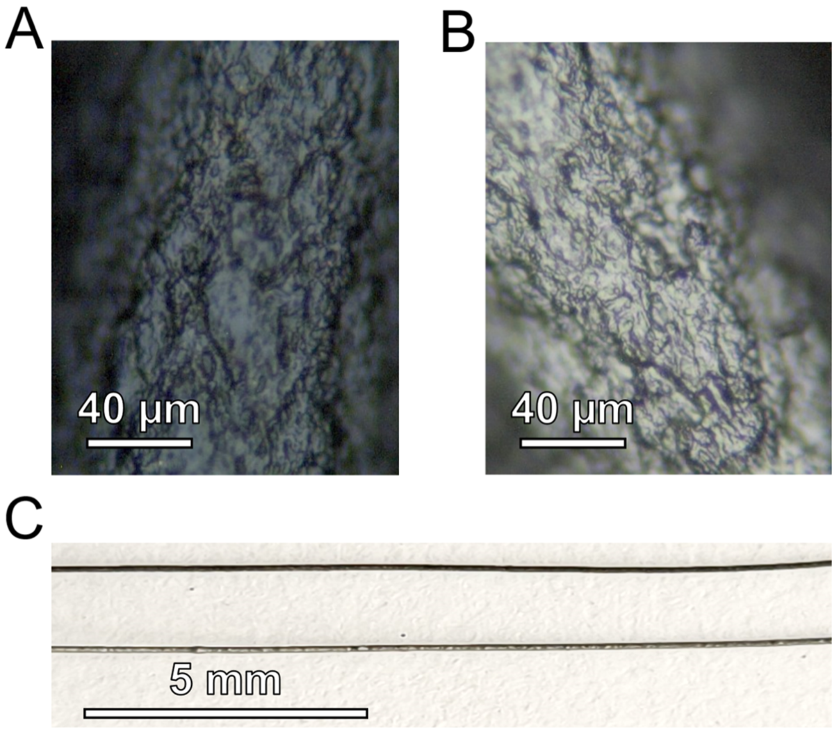

Figure 2. Optical images of Edison-like carbon filament. Microscopic images of the carbon filament from the Edison-like carbon light bulb filament (**A**) before and (**B**) after being subjected to 110 V for 20 s. (**C**) Photographic image on paper of raw filament (top) and filament after being subjected to 110 V for 20 s (bottom).

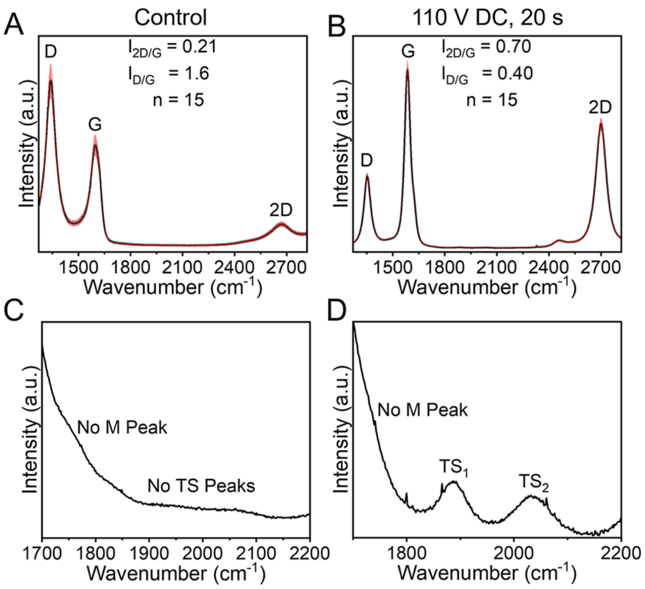

Figure 3. Raman spectra of raw carbon filament (control) compared to those of the carbon filament after heating at 110 V for 20 s. (A) Average Raman spectrum of the raw carbon filament. The mean spectrum is the thick black line, and the standard deviation (n = 15) is the red area around the mean. (B) Raman spectrum of the carbon filament after being Joule heated at 110 V DC for 20 s. Relative to the raw filament, the Joule heated filament exhibits a lower $I_{D/G}$ and a higher $I_{2D/G}$. (C) M and TS peak region of the Raman spectrum of the raw filament. No M or TS peaks are observed, indicating that the raw filament is neither graphene nor graphite. (D) TS peaks of the Raman spectrum of the filament after Joule heating.

graphene (Figure S3).[18] The raw carbon filament lacks both the M and TS peaks, indicating that there is no stacking order in the raw sample (Figure 2C). In contrast, the heated carbon filament exhibits prominent TS peaks and no M peak (Figure 2D), indicating the presence of turbostratic graphene and the absence of ordered graphene, AB- or ABC-stacked. The peak fitting of these TS peaks is exhibited in Figure S4. High-resolution Raman spectroscopy reveals their intensity relative to the G peaks as $I_{G/TS1}$ = 268 and $I_{G/TS2}$ = 341 (Figure S5). A spectrum of the graphene filament measured with a 785 nm laser is also exhibited in Figure S6.

A comparison of the Raman peak values of this carbon filament-derived turbostratic graphene to those of other turbostratic graphenes reported in the literature is shown in Table 3. Two other Raman studies have previously reported a prominent 2D Raman peak found in carbon filament light bulbs after being heated; however, one of these did not further characterize the filament,[28] while the other identified the filament as turbostratic graphite,[29] a 3-dimensional material, rather than turbostratic graphene, a layered, 2-dimensional material.[29] These two materials can be further distinguished from each other by their distinct spectroscopic and geometric features discussed in Supplementary Note 3 and 4 of this manuscript as well as in the seminal paper on flash turbostratic graphene published in 2020 in Nature.[18]

TEM images of the carbon filament were also taken before (Figure 4A) and after Joule heating (Figure 4B). The raw carbon filament before Joule heating is amorphous in morphology, with short-range ordering over the sample regions. After being Joule heat, the filament exhibits distinct graphene sheets with an interlayer spacing of 0.345 nm, typical of turbostratic graphene.[18]

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Table 3. Comparison of Turbostratic Graphene Parameters in the Literature with Experimental Data[a]

parameter	flash graphene in literature	filament graphene
TS_1 peak position	1886 cm^{-1} (ref 18) 1885 cm^{-1} (ref 26)	1887 cm^{-1}
TS_1 peak fwhm	34 cm^{-1} (ref 18) ~40–50 cm^{-1} (ref 26)	44 cm^{-1}
TS_2 peak position	2031 cm^{-1} (ref 18) 2033 cm^{-1} (ref 26)	2038 cm^{-1}
TS_2 peak fwhm	53 cm^{-1} (ref 18) ~50–60 cm^{-1} (ref 26)	61 cm^{-1}
M peak	none (refs 18 and 26)	none
2D location	2699 cm^{-1} (ref 18) 2684–2693 cm^{-1} (ref 26)	2701 cm^{-1}
2D fwhm	26 cm^{-1} (ref 18) ~50–70 cm^{-1} (ref 26)	70 cm^{-1}
$I_{2D/G}$	~0.7–1 (ref 18) ~0.5–0.9 (ref 26)	0.70
$I_{D/G}$	~0.1 (ref 18) ~0.1–0.6 (ref 26)	0.40
interlayer spacing	0.345 nm (ref 18)	0.345 nm

[a] A Raman excitation wavelength of 532 nm (corresponding to 2.33 eV) was used for this comparison.

4. PERSPECTIVES AND OUTLOOK

Imposing a voltage of 110 V DC across the carbon filament of an Edison-style incandescent bulb converts the filament to turbostratic graphene, consistent with the FJH process. While it cannot be known for certain, the evidence presented here strongly suggests that Thomas Edison may have synthesized graphene in 1879. This would place his work 85 years before Boehm and 126 years before the announcement of top-down graphene exfoliation by Novoselov and Geim.[6] It raises a provocative idea: the first graphene may not have been made by scientists studying two-dimensional materials but by an inventor working to improve electric lighting.

This reinterpretation of Edison's lamp reframes how we understand both the origins and the range of applicability of FJH. The lamp operated as a sealed, self-heating, electrically driven system at temperatures above 2000 °C, effectively mirroring many conditions used in modern flash processes. The use of simple geometries and scalable materials, along with highly reproducible carbon structures, reveals that several foundational principles of today's materials synthesis were present in Edison's time, even if unrecognized.

Several forward-looking opportunities arise from this insight. First, the operating conditions in Edison's setup provide a natural model reactor for studying graphene formation under steady voltage and inert conditions. Modern tools such as in situ Raman spectroscopy, optical emission diagnostics, and infrared pyrometry could now be applied to these historical systems to resolve thermal gradients, reaction mechanisms, and phase transformations with unprecedented detail. Second, the filament geometry allows controlled experiments of defect formation and structural evolution in turbostratic graphene. Changing the precursor material, filament size, or voltage profile offers a low-cost way to probe the physics of rapid thermal carbonization.

More broadly, this result encourages a re-examination of other early technologies through the lens of modern materials science. Devices such as vacuum tubes, arc lamps, and early X-ray tubes may have produced unusual materials or reactions that were never analyzed at the time. Revisiting these technologies with today's instrumentation may reveal previously unnoticed phenomena and could inspire new low-energy, low-infrastructure processing methods grounded in historical simplicity.

Recognizing that Edison's carbon filament may have been the first synthetic graphene is not only a matter of historical clarification. It also suggests that innovation can emerge from reinterpreting the past with fresh tools and new questions. In the case of "Edison graphene", a 140 year old invention continues to shed light, not just literally but scientifically.

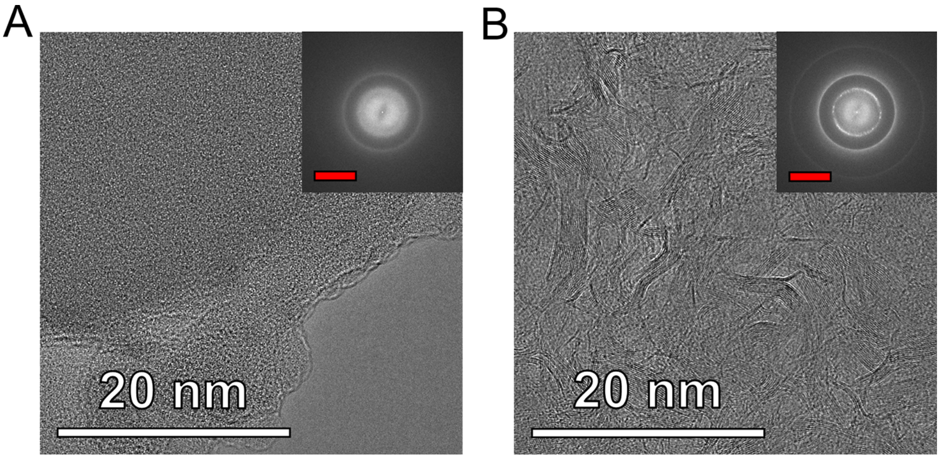

Figure 4. TEM image of the raw carbon filament before and after Joule heating. (A) TEM image of the raw carbon filament. The filament is predominantly amorphous in morphology before being Joule-heated. The inset image of the fast Fourier transform of this region demonstrates minimal ordering in the structure. The inset scale bar is 5 nm^{-1}. (B) TEM image of the turbostratic graphene filament that was synthesized after heating the filament at 110 V DC for 20 s. Distinct graphene layers are observed within the filament, among some regions of unconverted amorphous carbon. The inset image of the fast Fourier transform demonstrates significant graphitic ordering and a (002) peak corresponding to an interlayer spacing of 0.345 nm. The inset scale bar is 5 nm^{-1}.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsnano.5c12759.

Materials and methods; Raman spectroscopy analysis; TEM analysis; and Brodie's alleged synthesis of graphene oxide, variation in light bulb temperature, turbostratic graphene, and turbostratic graphene vs turbostratic graphite (PDF)

AUTHOR INFORMATION

Corresponding Author

James M. Tour − *Applied Physics Graduate Program and Smalley-Curl Institute, Rice University, Houston, Texas 77005, United States; Department of Chemistry, Department of Materials Science and NanoEngineering, The NanoCarbon Center and the Rice Advanced Materials Institute, and Department of Computer Science, Rice University, Houston, Texas 77005, United States;* orcid.org/0000-0002-8479-9328; Email: tour@rice.edu

Authors

Lucas Eddy − *Applied Physics Graduate Program and Smalley-Curl Institute, Rice University, Houston, Texas 77005, United States; Department of Chemistry, Rice University, Houston, Texas 77005, United States*

Chi Hun Choi − *Department of Materials Science and NanoEngineering, Rice University, Houston, Texas 77005, United States*

Justin Sharp − *Department of Chemistry, Rice University, Houston, Texas 77005, United States*

Carter Kittrell − *Department of Chemistry, Rice University, Houston, Texas 77005, United States;* orcid.org/0000-0002-8449-4292

Yimo Han − *Applied Physics Graduate Program and Smalley-Curl Institute, Rice University, Houston, Texas 77005, United States; Department of Materials Science and NanoEngineering, Rice University, Houston, Texas 77005, United States;* orcid.org/0000-0003-0563-4611

Complete contact information is available at:
https://pubs.acs.org/10.1021/acsnano.5c12759

Notes

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The authors declare the following competing financial interest(s): JMT is a shareholder in Universal Matter Inc., a company commercializing the synthesis of flash graphene by flash Joule heating. He is not an officer, director or employee of that company. Potential conflicts of interest are mitigated through regular disclosures to and compliance with the Rice University Office of Research Integrity.

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