**Discovery of Q-carbon, Q-BN, C-BN, and Diamond Related Materials**

[**https://www.mse.ncsu.edu/narayan/**](https://www.mse.ncsu.edu/narayan/) **(Q-carbon Discovery)**

**Google Q-carbon: Search Results**

**Web results (July 10, 2020):**

 **About 899,000,000 results (0.46 seconds)**

Q-carbon - Wikipedia

https://en.wikipedia.org/wiki/Q-carbon

**Q-carbon** (quenched carbon) is an allotrope of carbon, discovered in 2015, that is ferromagnetic, electrically conductive, and glows when exposed to low levels of energy. It is relatively inexpensive to make, and some news reports claim that it has replaced diamond as the world's hardest substance.

‎[Discovery](https://en.wikipedia.org/wiki/Q-carbon#Discovery) · ‎[Production](https://en.wikipedia.org/wiki/Q-carbon#Production) · ‎[Properties](https://en.wikipedia.org/wiki/Q-carbon#Properties)

[**https://www.google.com/search?q=q+carbon&rlz=1C1GGRV\_enUS751US751&oq=q&aqs=chrome.2.69i59j69i57j35i39j69i60l3.4238j0j3&sourceid=chrome&ie=UTF-8**](https://www.google.com/search?q=q+carbon&rlz=1C1GGRV_enUS751US751&oq=q&aqs=chrome.2.69i59j69i57j35i39j69i60l3.4238j0j3&sourceid=chrome&ie=UTF-8)

**A: Discovery of Q-carbon and Direct Conversion of Carbon into Q-carbon, Diamond, and Graphene**

**B: Discovery of Q-BN and Direct Conversion of BN into Q-BN, c-BN, and h-BN (wafer-scale)**

**Modern demands for energy-efficient power electronics, secure high-speed communications, and ever-increasing computing power are converging with technology opportunities created by ultrawide-bandgap semiconductors to define new paradigms for a wide range of electronic, optical, sensing, and quantum applications. Diamond and c-BN related materials represent ultimate semiconductor materials for next-generation solid state devices for the above applications. Considering Johnson’s (relevant for high-power devices) and Keys (relevant for microelectronics) figures of merit, diamond and c-BN are 8200 and 32 times better than silicon devices. However, diamond and c-BN are metastable materials at ambient temperatures and pressures, therefore, new nonequilibrium methods for synthesis and processing and doping are needed to fabricate novel solid state devices. Our recent breakthrough has resulted in direct conversion of carbon into diamond, graphene, and a new phase of Q-carbon with many extraordinary properties by nanosecond laser processing. There is also a parallel process leading to direct conversion of BN into Q-BN, c-BN, and h-BN. These materials now can be doped with both p-type and n-type (unlike only p-type doping in diamond so far) dopants with concentrations exceeding thermodynamic solubility limits. The diamond c-BN thin film heterostructures can be grown with wafer-scale integration for next-generation solid state devices, which is accomplished by overlapping laser pulses with throughput exceeding 100-200cm2s-1.**

**These discoveries are unprecedented in the field of materials science and engineering (Published over 50 high-impact papers, received 8 US Patents, 8 International Patents, 2017 R&D-100 Award for Q-carbon and diamond structures, 2018 R&D-100 Award for super hardness and record BCS superconductivity, and 2019 R&D-100 Award for Novel Nanodiamonds for Nanosensing and Quantum Computing (N3C). The R&D-100 Awards are known as “Oscars of Innovation.”**

**Research Funding: NSF, ARO, DARPA, DOE (ORNL)**

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**Brief History of Laser Annealing**

1**) Laser Annealing in Si and Ge**

CW White, J. Narayan, and RT Young, **Science** 204, 461 (1979).

Defects in Semiconductors and Laser Annealing launched MRS

2) **Laser Annealing in Carbon Implanted Copper**

J. Narayan, VP Godbole and CW White, **Science** 252, 416 (1991)

Formation of epitaxial diamond thin films

**Q-carbon: US Patents Granted to Jagdish Narayan (USPTO Website)**

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| --- | --- | --- |
|  **PATENT NO.** |  |  |
| 12 | **11,011,514**[10,586,702](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [DOPING AND FABRICATION OF DIAMOND AND C-BN BASED DEVICE STRUCTURES](http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.html&r=2&p=1&f=G&l=50&d=PG01&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish)[Synthesis and processing of novel phase of carbon (Q-carbon)](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 3 | [10,566,193](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=2&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Synthesis and processing of Q-carbon, graphene, and diamond](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=2&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 4 | [10,529,564](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=3&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Synthesis and processing of novel phase of boron nitride (Q-BN)](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=3&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 5 | [10,240,251](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=4&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Synthesis and processing of pure and NV nanodiamonds and other nanostructures for quantum computing and magnetic sensing applications](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=4&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 6 | [10,211,049](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=5&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Synthesis and processing of pure and NV nanodiamonds and other nanostructures](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=5&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 7 | [10,196,754](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=6&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Conversion of carbon into n-type and p-type doped diamond and structures](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=6&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 8 | [5,221,411](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=20&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Method for synthesis and processing of continuous monocrystalline diamond thin films](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=20&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 9  | [10,906,104](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |  | [Systems and methods of fabrication and use of wear-resistant materials](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&p=1&f=G&l=50&d=PTXT&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |

**US Patents Pending**

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| **PUB. APP. NO.** | **Title** |
| 1 | [20200149151](http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.html&r=1&p=1&f=G&l=50&d=PG01&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) | [DIAMOND NANOFIBERS AND METHODS OF MAKING DIAMOND NANOFIBERS AND LARGE-SIZE DIAMONDS](http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.html&r=1&p=1&f=G&l=50&d=PG01&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
| 2 | [20190363078](http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.html&r=2&p=1&f=G&l=50&d=PG01&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) | [DOPING AND FABRICATION OF DIAMOND AND C-BN BASED DEVICE STRUCTURES](http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.html&r=2&p=1&f=G&l=50&d=PG01&S1=Narayan-Jagdish&OS=Narayan-Jagdish&RS=Narayan-Jagdish) |
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**Q-carbon Related R&D-100 Awards (Oscars of Innovation) to Prof. J. Narayan’s Group**

1. **R&D-100 Award for Novel Nanodiamonds for Nansensing and Quantum Computing, 2019**
2. **R&D-100 Award for Q-carbon and Diamond Related Products, 2017**
3. **R&D-100 Award for New Materials Harder than Diamond and Superior High-Temp Superconductor, 2018**

**Independent Q-carbon Confirmation:**

Formation of Q-carbon by adjusting sp3 content in diamond-like

carbon films and laser energy density of pulsed laser annealing

Hiroki Yoshinaka a, Seiko Inubushi b, Takanori Wakita b, Takayoshi Yokoya b,

Yuji Muraoka b, \* **Carbon 167, 504-511 (2020).**

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[**Heavy boron doping in superconducting carbon materials**](https://apps-webofknowledge-com.prox.lib.ncsu.edu/full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=8DmmoTEkNxmZXrq2oY1&page=1&doc=1&cacheurlFromRightClick=no)

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