Qing Cao

Curriculum Vita

Address: Seitz Materials Research Laboratory
University of Illinois at Urbana-Champaign
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PROFESSIONAL APPOINTMENTS

University of Illinois at Urbana-Champaign: Urbana, IL.

October 2018-prsent

Associate Professor of Materials Science and Engineering, with affiliated appointments in Chemistry, Electrical and Computer Engineering, and Seitz Materials Research Lab

IBM Thomas J. Watson Research Center: Yorktown Heights, NY.

November 2011−October 2018

Research Staff Member **—** Launched research efforts on developing carbon nanotube transistor technology for scaling high-performance logic devices beyond the 5-nm technology node. Developed new approaches to sort nanotubes, assemble them into aligned arrays with unprecedented high density, and form end-bonded contacts to nanotubes with low, side-independent resistance. Based on these achievements, demonstrated nanotube transistors with extremely-scaled 40 nm device footprint and performance better than best-competing silicon devices, a major milestone in the development of nanotube technology. Established new basic scientific understandings on the nanotube-metal contacts and the variability of nanotube transistors.

February 2009−November 2011

Postdoctoral Scientist **—** Conducted research on copper-indium-gallium-selenide (CIGS) solar cells. Established new basic scientific understanding on the correlation among material structural defects, deep-level recombination centers, and device power-conversion efficiency. Scaled-up the deposition of CIGS from solution for integration into solar modules, in the Thin-Film Photovoltaic project jointed developed by IBM and several external companies.

EDUCATION

University of Illinois at Urbana-Champaign

Ph.D. degree in Materials Chemistry (Advisor: Prof. John A. Rogers), January 2009.

Thesis: Fundamental and Applied Aspects of Electronics Based on Carbon Nanotube Thin Films.

Nanjing University, China

B.S. degree in Chemistry, June 2004.

AWARDS AND HONORS

- Fellow of the World Innovation Organization Sponsored by the United Nations Development Programme (UNDP) 2017
- Invited Attendee at the Misk− UNDP Youth Forum of 2017 2017
- Millennium Fellow of the Atlantic Council 2017
- I.B.M. Pat Goldberg Memorial Best Paper Award 2017
- I.B.M. Master Inventor Recognition 2016

- 35 Innovators under 35 (*TR35*) by MIT Technology Review 2016
- U.S. Frontiers of Engineering by National Academy of Engineering 2016
- I.B.M. Research Division Award 2016
- "*All-Star Alumni*" of Forbes 30 Under 30s 2016
- I.B.M. Corporation Outstanding Technical Achievement Award 2015
- Forbes Magazine "*30 under 30*" list of rising stars in Science and Healthcare 2012
- I.B.M. Corporation Invention Achievement Award (fifteen times) 2009-2017
- Chinese Government Award for Outstanding Self-Financed Students Abroad 2009
- Materials Research Society Graduate Student Silver Award 2008
- University of Illinois Lester E. and Kathleen A. Coleman Fellowship 2006
- Nanjing University Outstanding Graduate Award 2004

SELECTED PUBLICATIONS (* indicates corresponding author)

35 papers in journals including *Nature, Science, Nature Nanotechnology, Nature Communications, Advanced Materials, Advanced Energy Materials, Physical Review Applied, ACS Nano, Applied Physics Letters*, etc. 4 conference proceedings. 3 book chapters.

1) **Q. Cao***, J. Tersoff, D. B. Farmer, Y. Zhu, and S.-J. Han, "Carbon nanotube transistors scaled to a 40-nanometer footprint," *Science* 356(6345), 1369-1372 (2017).
   Highlighted by *Science*: Scientists use carbon nanotubes to make the world's smallest transistors.
   ***IEEE Spectrum*:** Carbon nanotubes reduce transistor footprint to forty nanometers.
   ***Neue Zürcher Zeitung* (*New Journal of Zurich*):** Nanoröhren schalten auf engstem raum.
   ***Next Big Future*:** IBM has made carbon nanotubes transistors smaller and faster than silicon.
   ***Science News Magazine*:** The incredible shrinking transistor just got smaller.
   ***Physics Today*:** Carbon nanotube transistors are scaled down to record size.
2) **Q. Cao***, S.-J. Han, J. Tersoff, A. D. Franklin, Y. Zhu, Z. Zhang, G. S. Tulevski, J.-S. Tang, and W. Haensch, "End-bonded contacts for carbon nanotube transistors with low, size-independent resistance," *Science* 350(6256), 68-72 (2015).
   Highlighted by *New York Times*: IBM scientists find new way to shrink transistors.
   ***Time*:** IBM's new research could mean much more powerful computers.
   ***Fortune*:** IBM aims to replace silicon transistors with carbon nanotubes to keep up with Moore's Law.
   ***Daily Mail*:** The end of silicon? IBM reveals carbon nanotube breakthrough that could revolutionise computing and lead to ultrafast artificial intelligence "brain chips".
   ***Wall Street Journal*:** Carbon nanotube valley?
   ***Reuters*:** IBM research breakthrough paves way for post-silicon future with nanotube electronics.
   ***Forbes*:** Carbon nanotubes are getting closer to making our electronic devices obsolete.
   ***MIT Technology Review*:** IBM reports breakthrough on carbon nanotube transistors.
   ***IEEE Spectrum*:** IBM solves nanotube transistor's big shrinking problem.
   ***Nature Nanotechnology*:** Less is Moore.
3) **Q. Cao**, H.-S. Kim, N. Pimparkar, J. P. Kulkarni, C. Wang, M. Shim, K. Roy, M. A. Alam, and J. A. Rogers*, "Medium-scale carbon nanotube thin-film integrated circuits on flexible plastic substrates," *Nature* 454, 495-500 (2008).
   Highlighted by *Chemical and Engineering News*: Flexible circuits from carbon nanotubes.

***Chemistry World*:** Nanotube mesh boosts plastic electronics.
***MIT Technology Review*:** Bendable nanotube circuits.
***R&D Magazine*:** The way to close a "nanonet" is by cutting it into pieces.
***Science Daily*:** "Nanonet" circuits closer to making flexible electronics reality.
***Nanotechweb*:** Flexible CNT circuits move on.

4) **Q. Cao*,** S.-J. Han, G. S. Tulevski, Y. Zhu, D. D. Lu, and W. Haensch, "Arrays of single-walled carbon nanotubes with full surface coverage for high-performance electronics," *Nature Nanotechnol.* 8, 180-186 (2013).
   Highlighted by *Nature Nanotechnology*: Nanotube arrays made to order.
   ***MRS Bulletin*:** High-performing transistors fabricated with single-walled carbon nanotube arrays.
   ***PhysOrg*:** Densest array of carbon nanotubes paves way toward post-silicon technology.
   ***Nanotechweb*:** CNT arrays make record-breaking transistors.
5) **Q. Cao***, S.-J, Han, and G. S. Tulevski, "Fringing-field dielectrophoretic assembly of ultrahigh-density semiconducting nanotube arrays with a self-limited pitch," *Nature Commun*. 5, 5071 (2014).
6) **Q. Cao***, S.-J. Han, A. V. Penumatcha, M. M. Frank, G. S. Tulevski, J. Tersoff, and W. E. Haensch, "Origins and characteristics of the threshold voltage variability of quasiballistic single-walled carbon nanotube field-effect transistors," *ACS Nano* 9(2), 1936-1944 (2015). [**Highlighted by *Nanotechweb*:** CNTs show feasibility for practical devices.]
7) **Q. Cao***, J. Tersoff, S.-J. Han, and A. V. Penumatcha, "Scaling of device variability and subthreshold swing in ballistic carbon nanotube transistors," *Phys. Rev. Appl.* 4(2), 024022 (2015). **[Featured in Editor's Suggestion]**
8) **Q. Cao***, S.-J. Han, "Single-walled carbon nanotubes for high-performance electronics," *Nanoscale* 5, 8852-8863 (2013). **[Invited feature article]**
9) **Q. Cao***, S.-J. Han, G. S. Tulevski, A. D. Franklin, and W. Haensch, "Evaluation of field-effect mobility and contact resistance of transistors that use solution-processed single-walled carbon nanotubes," *ACS Nano* 6(7), 6471-6477 (2012).
10) **Q. Cao**, O. Gunawan, M. Copel, K. B. Reuter, S. J. Chey, V. R. Deline, and D. B. Mitzi*, "Defects in Cu(In,Ga)Se_2 chalcopyrite semiconductors: a comparative study of material properties, defect states, and photovoltaic performance," *Adv. Energy Mater.* 1, 845-853 (2011). **[Frontispiece feature article, Highlighted by *Materials Views*:** Toward more efficient thin-film solar cells.**]**

SELECTED PATENTS

Over 50 patents and patent applications in areas ranging from novel logic devices to solar cells to nanofabrication to memory technologies and flexible electronics. Three of them as listed below are rated as *High Value Patents* by IBM.

1) **Q. Cao**, A. D. Franklin, and J. T. Smith, "Double contacts for carbon nanotubes thin film devices," U.S. Patent No. US 8754393 B2.
2) **Q. Cao**, N. Li, J.-S. Tang, "Metal semiconductor field-effect transistor with carbon nanotube gate," U.S. Patent Application No. US 15/277393.
3) **Q. Cao**, N. Li, "Semiconductor device with a steep subthreshold slope," U.S. Patent Application No. 15/222324.

SELECTED INVITED TALKS

~20 invited talks and key-note lectures in conferences and research institutions.

1) "Carbon nanotube transistor technology for extremely-scaled logic devices" at Center for Nanoscale Systems, Harvard University, Boston, MA, October 2017.
2) "The future of the workforce" at the *Concordia Annual Summit*, New York, NY, September 2017.
3) "Carbon nanotube for extremely scaled logic transistors to the end of the technology roadmap" at the *18th International Conference on the Science and Application of Nanotubes and Low-dimensional Materials*, Belo Horizonte, Brazil, June 2017.
4) "Carbon nanotube transistor technology for the 5-nm technology node and beyond" at the *Nanotech 2017 Conference and Expo*, Washington, DC, May 2017.
5) "Extending Moore's law with carbon nanotube transistors" at *2016 TTI/Vanguard [Next] Conference*, San Francisco, CA, December 2016.
6) "High-performance logic electronics based on carbon nanotubes for 5-nm technology node and beyond" at the *Materials Research Society 2016 Fall Meeting*, Boston, MA, November 2016.
7) "Carbon nanotube transistor technology for scaling beyond Si CMOS" at the *48th International Conference on Solid State Devices and Materials (SSDM)*, Tsukuba, Japan, September, 2016.
8) "High density semiconducting nanotube arrays for high performance electronics" at the *51st Annual Technical Meeting of the Society of the Engineering Sciences*, West Lafayette, IN, October 2014.
9) "*En route* toward high performance electronics based on single-walled carbon nanotubes" at the *SPIE: Defense + Security*, Baltimore, MD, May 2014.
10) "Full-coverage semiconducting nanotube arrays for high performance electronics" at the *7th International Conference on Materials for Advanced Technologies (ICMAT13)*, Singapore, July 2013.
11) "Carbon nanotubes for high-performance logic electronics", key note lecture at the *Fourteenth International Conference on the Science and Application of Nanotubes (NT13)*, Helsinki, Finland, June 2013.

PROFESSIONAL ACTIVITIES AND SERVICES

Journal reviewer for *Science, Science Advances, Nature Nanotechnology, Nature Catalysis, Nature Communications, Advanced Materials, ACS Nano, Chemistry of Materials, ACS Applied Materials & Interfaces, Nanoscale, Physical Review Applied, Applied Physics Letters, Journal of Applied Physics, Nanotechnology, New Journal of Physics, Journal of Physics D: Applied Physics, IEEE Electron Device Letters, IEEE Transactions on Nanotechnology, Chemical Communications, Physical Chemistry Chemical Physics, Journal of Materials Chemistry, Environmental Science and Technology.*

Grant Reviewer for *US National Science Foundation* and *Applied Research Grant of Hong Kong.*

Meeting Chair of *2020 MRS Spring Meeting & Exhibit*

IBM Materials Research Community Committee Member 2013−2018

Technical Program Committee Member: *IEEE 12th International Conference on Nanotechnology*

Qing Cao

Full Publication List

PEER-REVIEWED JOURNAL PUBLICATIONS (* indicates corresponding author)

1) J.-S. Tang, **Q. Cao**, G. S. Tulevski, K. A. Jenkins, L. Nela, D. B. Farmer and S.-J. Han, "Flexible CMOS integrated circuits based on carbon nanotubes with sub-10 ns stage delays," *Nature Electron.* 1, 191-196 (2018).
2) L. Nela, J.-S. Tang* , **Q. Cao**, G. S. Tulevski, and S.-J. Han*, " Large-area high-performance flexible pressure sensor with carbon nanotube active matrix for electronic skin," *Nano Lett.* 18 (3), 2054-2059 (2018).
3) **Q. Cao***, J. Tersoff, D. B. Farmer, Y. Zhu, and S.-J. Han, "Carbon nanotube transistors scaled to a 40-nanometer footprint," *Science* 356(6345), 1369-1372 (2017). **[Highlighted by *Science, IEEE Spectrum, New Journal of Zurich, Next Big Future, Science News Magazine, Physics Today*, and more]**
4) A. L. Falk*, K.-C. Chiu, D. B. Farmer, **Q. Cao**, J. Tersoff, Y.-H. Lee, Ph. Avouris, and S.-J. Han, "Coherent plasmon and phonon-plasmon resonances in carbon nanotubes," *Phys. Rev. Lett.* 118(25), 257401 (2017).
5) J.-S. Tang*, **Q. Cao**, D. B. Farmer, G. S. Tulevski, and S.-J. Han, "High-performance carbon nanotube complementary logic with end-bonded contacts," *IEEE Trans. Electron Devices* 64(6), 2744-2750 (2017).
6) J. Wang, T. D. Nguyen, **Q. Cao***, Y. L. Wang, M. Y. C. Tan, and M. B. Chan-Park*, "Selective surface charge sign reversal on metallic carbon nanotubes for facile ultra-high purity nanotube sorting," *ACS Nano* 10(3), 3222-3232 (2016).
7) **Q. Cao***, S.-J. Han, J. Tersoff, A. D. Franklin, Y. Zhu, Z. Zhang, G. S. Tulevski, J.-S. Tang, and W. Haensch, "End-bonded contacts for carbon nanotube transistors with low, size-independent resistance," *Science* 350(6256), 68-72 (2015). **[Highlighted by *New York Times, Time, Fortune, Daily Mail, Wall Street Journal, Washington Post, Forbes, Reuters, MIT Technology Review, IEEE Spectrum, EE Times, Wired, CNET, Engadget, PC Magazine, PC World, Physorg, Nature Nanotechnology, Information Week*, and more]**
8) **Q. Cao***, J. Tersoff, S.-J. Han, and A. V. Penumatcha, "Scaling of device variability and subthreshold swing in ballistic carbon nanotube transistors," *Phys. Rev. Appl.* 4(2), 024022 (2015). **[Featured in Editor's Suggestion]**
9) **Q. Cao***, S.-J. Han, A. V. Penumatcha, M. M. Frank, G. S. Tulevski, J. Tersoff, and W. E. Haensch, "Origins and characteristics of the threshold voltage variability of quasiballistic single-walled carbon nanotube field-effect transistors," *ACS Nano* 9(2), 1936-1944 (2015). **[Highlighted by *Nanotechweb*]**
10) G. S. Tulevski*, A. D. Franklin, D. Frank, J. M. Lobez, **Q. Cao**, H. Park, A. Afzali, S.-J. Han, J. B. Hannon, and W. Haensch, "Toward high-performance digital logic technology with carbon nanotubes," *ACS Nano* 8 (9), 8730-8745 (2014).
11) **Q. Cao***, S.-J, Han, and G. S. Tulevski, "Fringing-field dielectrophoretic assembly of ultrahigh-density semiconducting nanotube arrays with a self-limited pitch," *Nature Commun*. 5,

5071 (2014).

12) **Q. Cao***, S.-J. Han, "Single-walled carbon nanotubes for high-performance electronics," *Nanoscale* 5(19), 8852-8863 (2013). **[Invited Feature Article]**

13) **Q. Cao*,** S.-J. Han, G. S. Tulevski, Y. Zhu, D. D. Lu, and W. Haensch, "Arrays of single-walled carbon nanotubes with full surface coverage for high-performance electronics," *Nature Nanotechnol.* 8(3), 180-186 (2013). **[Highlighted by *Nature Nanotechnology, MRS Bulletin, PhysOrg*, and *Nanotechweb*]**

14) **Q. Cao***, S.-J. Han, G. S. Tulevski, A. D. Franklin, and W. Haensch, "Evaluation of field-effect mobility and contact resistance of transistors that use solution-processed single-walled carbon nanotubes," *ACS Nano* 6(7), 6471-6477 (2012).

15) A. D. Franklin*, G. S. Tulevski, S.-J. Han, D. Shahrjerdi, **Q. Cao**, H.-Y. Chen, H. -S. P. Wong, and W. Haensch, "Variability in carbon nanotube transistors: improving device-to-device consistency," *ACS Nano* 6(2), 1109-1115 (2012).

16) **Q. Cao**, O. Gunawan, M. Copel, K. B. Reuter, S. J. Chey, V. R. Deline, and D. B. Mitzi*, "Defects in Cu(In,Ga)Se_2 chalcopyrite semiconductors: a comparative study of material properties, defect states, and photovoltaic performance," *Adv. Energy Mater.* 1(5), 845-853 (2011). **[Frontispiece feature article, Highlighted by *Materials Views*]**

17) X. Ho, L. Ye, S. V. Rotkin, **Q. Cao**, S. Unarunotai, S. Salamat, M. A. Alam and J. A. Rogers*, "Scaling properties in transistors that use aligned arrays of single-walled carbon nanotubes," *Nano Lett.* 10(2), 499-503 (2010).

18) C. Kocabas, S. Dunham, **Q. Cao**, K. Cimino, X. Ho, H.-S. Kim, D. Dawson, J. Payne, M. Stuenkel, H. Zhang*, T. Banks, M. Feng, S. V. Rotkin and J. A. Rogers*, "High-frequency performance of submicrometer transistors that use aligned arrays of single-walled carbon nanotubes," *Nano Lett.* 9(5), 1937-1943 (2009).

19) N. Pimparkar, **Q. Cao**, J. A. Rogers*, and M. A. Alam*, "Theory and practice of "stripping" for improved on/off ratio in carbon nanonet thin film transistors," *Nano Research* 2(2), 167-175 (2009).

20) **Q. Cao** and J. A. Rogers*, "Ultrathin films of single-walled carbon nanotubes for electronics and sensors: a review of fundamental and applied aspects," *Adv. Mater.* 21(1), 29-53 (2009). **[Featured in *Advances in Advance*, Most Accessed Article in December, 2008]**

21) **Q. Cao** and J. A. Rogers*, "Random networks and aligned arrays of single-walled carbon nanotubes for electronic device applications," *Nano Research* 1(4), 259-272 (2008). **[Invited Review]**

22) **Q. Cao**, H.-S. Kim, N. Pimparkar, J. P. Kulkarni, C. Wang, M. Shim, K. Roy, M. A. Alam, and J. A. Rogers*, "Medium-scale carbon nanotube thin-film integrated circuits on flexible plastic substrates," *Nature* 454(7203), 495-500 (2008). **[Highlighted by *Chemical and Engineering News, Chemistry World, MIT Technology Review, Semiconductor International, R&D Magazine, Science Daily, Small Times, Science Centric, Ars Technica, I-Micronew Magazine, Nanotechweb, Physorg*, and more]**

23) M. J. Schultz, X.-Y. Zhang, S. Unarunotai, D.-Y. Khang, **Q. Cao**, C.-J. Wang, C.-H. Lei, S. McLaren, J. Soares, I. Petrov, J. S. Moore*, and J. A. Rogers*, "Crosslinked, conjugated carbon monolayers: films, balloons, tubes and pleated Sheets," *Proc. Natl. Acad. Sci. U. S. A.* 105(21), 7353-7358 (2008). **[Highlighted by *Chemistry World and Nanowerk*]**

24) S. J. Kang, C. Kocabas, H.-S. Kim, **Q. Cao**, M. A. Meitl, D.-Y. Khang, and J. A. Rogers*, "Printed

multilayer superstructures of aligned single-walled carbon nanotubes for electronic applications," *Nano Lett.* 7(11), 3343-3348 (2007).

25) **Q. Cao**, M.-G. Xia, C. Kocabas, M. Shim, S. V. Rotkin*, and J. A. Rogers*, "Gate capacitance coupling of single-walled carbon nanotube thin-film transistors," *Appl. Phys. Lett.* 90(2), 023516 (2007).
26) N. Pimparkar, **Q. Cao**, S. Kumar, J. Y. Murthy, J. A. Rogers, and M. A. Alam*, "Current-voltage characteristics of long-channel nanobundle thin-film transistors: a 'bottom-up' perspective," *IEEE. Electron. Device Lett.* 28(2), 157-160 (2007).
27) E.-L. Gui, L.-J. Li*, P. S. Lee, A. Lohani, S. G. Mhaisalkar, **Q. Cao**, S. J. Kang, J. A. Rogers, N. C. Tansil, and Z. Gao, "Electrical detection of hybridization and threading intercalation of deoxyribonucleic acid using carbon nanotube network field-effect transistors," *Appl. Phys. Lett.* 89(23), 232104 (2006).
28) **Q. Cao**, M.-G. Xia, M. Shim, and J. A. Rogers*, "Bilayer organic-inorganic gate dielectrics for high-performance, low-voltage single-walled carbon nanotube thin-film transistors, complementary logic gates and p-n diodes on plastic substrates," *Adv. Func. Mater.* 16(18), 2355-2362 (2006). **[Cover feature article]**
29) **Q. Cao**, Z.-T. Zhu, M. G. Lemaitre, M.-G. Xia, M. Shim, and J. A. Rogers*, "Transparent flexible organic thin-film transistors that use printed single-walled carbon nanotube electrodes," *Appl. Phys. Lett.* 88(11), 113511 (2006). **[Selected in *Virtual Journal of Nanoscale Science & Technology* published by APS]**
30) **Q. Cao**, S.-H. Hur, Z.-T. Zhu, Y.-G. Sun., C.-J. Wang, M. A. Meitl, M. Shim, and J. A. Rogers*, "Highly bendable, transparent thin-film transistors that use carbon-nanotube-based conductors and semiconductors with elastomeric dielectrics," *Adv. Mater.* 18(3), 304-309 (2006). **[Highlighted by *Chemical and Engineering News*]**
31) C.-J. Wang*, **Q. Cao**, T. Ozel, A. Gaur, J. A. Rogers, and M. Shim*, "Electronically selective chemical functionalization of carbon nanotubes: correlation between Raman spectral and electrical responses," *J. Am. Chem. Soc.* 127(32), 11460-11468 (2005).
32) F.-P. Zhang, **Q. Cao**, J.-J. Cheng, C.-H. Zhang, N. An, and S.-P. Bi*, "Electrochemical and spectrometric studies of double-strand calf thymus gland DNA denatured by Al(III) at neutral pH," *Anal. Sci.* 25(8), 1019-1023 (2009).
33) X.-F. Long, D.-S. Li, N. Wang, C.-H. Zhang, **Q. Cao**, T.-C. Xian, and S.-P. Bi*, "A novel and sensitive method for recognition and indirect determination of Al^{III} in biological fluid based on the quenching of resonance Rayleigh scattering intensities of 'Al^{III}-EV-DNA' complexing system," *Spectroc. Acta Pt. A-Molec. Biomolec. Spectr.* 69(1), 142-147 (2008).
34) Q. Miao, **Q. Cao,** and S.-P. Bi*, "Density functional theory study on the bridge structure in dimeric aluminum (III) water complexes," *J. Chem. Phys.* 121(10), 4650-4656 (2004).
35) S.-P. Bi*, C.-Y. Wang, **Q. Cao**, and C.-H. Zhang, "Studies on the mechanism of hydrolysis and polymerization of aluminum salts in aqueous solution: correlations between the 'Core-Links' Model and 'Cage-Like' Keggin-Al_{13} Model," *Coord. Chem. Rev.* 248(5), 441-455 (2004).

CONFERENCE PROCEEDINGS

1) J.-S. Tang, **Q. Cao**, D. B. Farmer, G. S. Tulevski, and S.-J. Han, "Carbon nanotube complementary

logic with low-temperature processed end-bonded metal contacts," *IEDM Tech. Digest*, 5.1.1-5.1.4 (2016) [**Highlighted by *EE Times***].

2) **Q. Cao**, "*En route* toward high performance electronics based on single-walled carbon nanotubes," *Proc. SPIE 9083, Micro- and Nanotechnology Sensors, Systems, and Applications VI*, 90830M (2014).
3) D. B. Mitzi, T. K. Todorov, O. Gunawan, M. Yuan, **Q. Cao**, W. Liu, K. B. Reuter, M. Kuwahara, K. Misumi, A. J. Kellock, S. J. Chey, T. G. de Monsabert, A. Prabhakar, V. Deline, and K. E. Fogel, "Towards marketable efficiency solution-processed kesterite and chalcopyrite photovoltaic devices," in *Photovoltaic Specialists Conference (PVSC)*, 640-645 (2010).
4) **Q. Cao**, C. Kocabas, and J. A. Rogers, "Carbon nanotube for high-performance flexible electronics," *Proc. 7th Electrochem. Soc.-Int. Semi. Tech. Conf.*, 690 (2008).

BOOK CHAPTERS

1) **Q. Cao**, and S.-J. Han, "Nanoelectronics based on singled-walled carbon nanotubes," In *Nanomaterials, Polymers, and Devices: Materials Functionalization and Device Fabrication*. Kong, E.S.W. Eds. Wiley-VCH (2015).
2) C. J. Wang, and **Q. Cao**, "Thin films of single-walled carbon nanotubes for flexible electronic device applications," In *Semiconductor Nanomaterials for Flexible Technologies*, Y. G. Sun, J. A. Rogers, Eds. Elsevier (2010).
3) **Q. Cao**, C. Kocabas, M. A. Meitl, S. J. Kang, J. U. Park, and J. A. Rogers, "Single-walled carbon nanotubes for high performance thin film electronics," In *Carbon Nanotube Electronics*, A. Javey, J. Kong, Eds. Springer Verlag GmbH Co.: KG (2008).

ISSUED PATENTS

1) **Q. Cao**, Y. He, and N. Li, "Biocompatible devices with dissolvable substrates and method of forming the same," U.S. Patent No. US 9,795,718.
2) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, "Prevention of reverse engineering of security chips," U.S. Patent No. US 9853001.
3) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, "Nanoparticle with plural functionalities, and method of forming the nanoparticle," U.S. Patent No. US 9859494.
4) **Q. Cao**, N. Li, and J.-S. Tang, "Metal semiconductor field effect transistor with carbon nanotube gate," U.S. Patent No. US 9887282.
5) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, "Integrated circuit having MIM capacitor with refractory metal silicided strap and method to fabricate same," U.S. Patent No. US 9659939.
6) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, "Carbon nanotube vacuum transistors," U.S. Patent No. US 9680116.
7) **Q. Cao**, K.-G. Cheng, and F. Liu, "Self-destructive circuits under radiation," U.S. Patent No. US 9685417.
8) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, "High density nano-array for sensing," U.S. Patent No. US 9612224.
9) **Q. Cao**, S.-J. Han, N. Li, and J.-S. Tang, "Semiconductor device with self-aligned carbon nanotube gate," U.S. Patent No. US 9704965.

10) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, “Multi-faced component-based electromechanical device,” U.S. Patent No. US 9701532.
11) **Q. Cao**, Y. He, and N. Li, “High-Z nanoparticles embedded in semiconductor package,” U.S. Patent No. US 9607952.
12) **Q. Cao**, K.-G. Cheng, S.-J. Han, Z.-W. Li, and F. Liu, “Fringing-field assisted dielectrophoresis assembly of carbon nanotubes,” US Patent No. US 9525147.
13) **Q. Cao**, K. Cheng, Z. Li, F. Liu, and Z. Zhang, “Transistor devices with tapered suspended vertical arrays of carbon nanotubes,” US Patent No. US 9502673.
14) **Q. Cao**, K. Cheng, Z. Li, and F. Liu, “Semiconductor device with authentication code,” US Patent No. US 9502405.
15) **Q. Cao**, S.-J. Han, and L-W. Hung, “Light sensitive switch for semiconductor package tamper detection,” US Patent No. US 9496230.
16) **Q. Cao**, K. Cheng, Z. Li, F. Liu, and Z. Zhang, “MIS-IL silicon solar cell with passivation layer to induce surface inversion,” US Patent No. US 9466755.
17) **Q. Cao**, K.-G. Cheng, and F. Liu, “Secure chip with physically unclonable function,” U.S. Patent No. US 9379184.
18) Z.-W. Li, **Q. Cao**, K.-G. Cheng, F. Liu, and Z. Zhang, “Carbon-doped cap for a raised active semiconductor region,” U.S. Patent No. US 9373702.
19) **Q. Cao**, K.-G. Cheng, Z.-W. Li, and F. Liu, “FinFET including varied fin height,” U.S. Patent No. US 9324792.
20) **Q. Cao**, K.-G. Cheng, Z.-W. Li, F. Liu, and Z. Zhang, “Colorimetric radiation dosimetry based on functional polymer and nanoparticle hybrid,” U.S. Patent No. US 9170337 B2.
21) **Q. Cao**, and S.-J. Han, “Formation of CMOS device using carbon nanotubes,” US Patent No. US9299939 B1.
22) **Q. Cao**, and S.-J. Han, “Forming p-n junction contacts by different dielectrics,” US Patent No. US9287516 B2.
23) **Q. Cao**, and S.-J. Han, “Reactive contacts for 2D layered metal dichalcogenides,” US Patent No. 9147824 B1.
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