Ultrananocrystalline Diamond

Diamond thin films have remarkable properties that have to potential to meet the rising demand for more efficient electronics that deliver and convert power. Argonne's portfolio of ultrananocrystalline diamond (UNCD) pending and issued intellectual property covers a suite of critical semiconductor processes such as chemical vapor deposition, which is the process of growing a layer of polycrystalline diamond on a semiconductor wafer or glass at low temperature, as well as doping, which refers to the process of intentionally introducing impurities into an extremely pure semiconductor in order to modulate its electrical properties. The portfolio also covers the formation of circuit elements such as transistors by integration with graphene, fabrication of microelectromechanical systems, which are then connected to form complex circuits, such as logic devices compatible complementary metal oxide semiconductor (CMOS) technology. This portfolio also includes the integration of electronic circuits that are built on a single semiconductor base material or single chip.

Various applications include, but are not limited to:

- RF/MEMS, robust MEMS with sliding/rotating contacts
- Flexible, transparent thin film transistor for flat panel displays
- Electrochemical sensors, semiconductor devices
- Thermal management for electronic devices and battery electrodes
- Field emission arrays for electron and x-ray sources
- In-vivo biomedical implants
- Biosensors
- Transparent, scratch resistance protective coatings on glass

Argonne National Laboratory: Ultrananocrystalline Diamond Intellectual Property				
Title	**Benefits**	**U.S. Patent/Patent App. No.**	**Co-Owned**	**ANL Invention**
Simple Method to Fabricate Nano-Porous Diamond Membranes	• Biocompatible for skin grafting, as well as for water purification applications	8,673,164 Issued March 18, 2014		IN-11-001
A Method To Achieve Isotropic Thermal Conductivity Using Diamond/Graphene Hetero-Structure		Presently unfiled		IN-14-011
Ultrananocrystalline diamond films with optimized dielectric properties for advanced RF MEMS capacitive switches	• A specialized radio frequency (RF) micro-electromechanical system (MEMS) switch that promises enhanced capabilities for next-generation military and commercial communication systems • Robust and reliable with extremely low power consumption; prevents overcharge and improves safety • CMOS compatible	8,354,290 Issued January 15, 2013		IN-09-070
UNCD Films with optimized dielectric properties for advanced RF MEMS capacitive switches	• A specialized radio frequency (RF) micro-electromechanical system (MEMS) switch that promises enhanced capabilities for next-generation military and commercial communication systems • Robust and reliable with extremely low power consumption; prevents overcharge and improves safety • CMOS compatible	9,269,519 Issued Feb. 23, 2016		IN-09-070C

RF MEMS Capacitive Switches With High Reliability	• A specialized radio frequency (RF) micro-electromechanical system (MEMS) switch that promises enhanced capabilities for next-generation military and commercial communication systems • Robust and reliable with extremely low power consumption; prevents overcharge and improves safety • CMOS Compatible	8,525,185, issued September 3, 2013	Yes	IN-09-053
Graphene Layer Formation at Low Substrate Temperature on a Metal and Carbon Based Substrate	• Direct growth of graphene on insulating substrate at wafer-scale • Order of magnitude increase in breakdown current density reaching up to one thousand times improvement over conventional metal based interconnects	8,906,772 Issued December 9, 2014		IN-11-055
Graphene Layer Formation at Low Substrate Temperature on a Metal and Carbon Based Substrate	• Direct growth of graphene on insulating substrate at wafer-scale • Order of magnitude increase in breakdown current density reaching up to one thousand times improvement over conventional metal based interconnects	14/563,201 Filed December 8, 2014 PCT/US15/064330 Filed Dec. 7, 2015		IN-11-055C
Graphene Layer Formation on a Carbon Based Substrate	• Direct growth of graphene on insulating substrate at wafer-scale • Order of magnitude increase in breakdown current density reaching up to one thousand times improvement over conventional metal based interconnects	8,652,946, issued February 18, 2014	Yes	IN-12-024
Graphene Layer Formation on a Carbon Based Substrate	• Direct growth of graphene on insulating substrate at wafer-scale • Order of magnitude increase in breakdown current density reaching up to one thousand times improvement over conventional metal based interconnects	9,202,684, issued December 1, 2015	Yes	IN-11-055B
Direct Synthesis of Reduced Graphene Oxide Films on Dielectric Substrates	• Optically transparent, CVD deposition of reduced graphene oxide film directly on the glass substrate • Wafer-scale synthesis in few mins • Pin-hole free deposition • Moderate sheet resistance at lower thickness • High thermal conductivity than Tin Oxide	Patent application filed 14/711,335 on May 13, 2015		IN-14-110
All 2D High Mobility, Flexible, Transparent, Thinnest Thin Transistor	• Flexible, transparent high mobility thin film transistor for flat panel display • 10 atomic layers thick • On/off ratio is as good as current commercial thin-film transistors	9,548,394 Issued January 17, 2017		IN-14-013
Giant PiezoResisitivity in Boron Doped Diamond Nanowire	• Increased sensitivity to applied strain for tactile sensing • More environmentally stable than conventional silicon-based piezoresistive sensors	9,441,940 Issued September 13, 2016 PCT/US2016/013708 Filed January 15, 2016		IN-14-016

Method To Deposit Optically Transparent And Scratch Resistant Nanocrystalline Diamond Glass At Low Temperatures	• Optically transparent, scratch resistant ultrathin film of diamond on glass for protective applications	14/796,527 filed July 10, 2015	Yes	IN-14-006
Semiconductor Devices Fabrication Based On Optically Transparent, Low Temperature Nanocrystalline Diamond On Glass, Quartz, And Sapphire	• Transparent semiconductor devices with high thermal conductivity	(filed with ANL-IN-14-006, above)	Yes	IN-14-007
Direct Integration Of Low Temperature Diamond With Semiconductor Materials For Efficient Thermal Management	• Thermal management of semiconductor devices	filed with ANL-IN-14-006, above)	Yes	IN-14-010
Transparent Electronic System and Method	• Transparent semiconductor devices with high thermal conductivity	Prov. Patent App. No. 61/977,151, filed April 9, 2014; U.S. Patent App. No. 14/682,947 filed April 9, 2015	Yes	IN-14-052
Method to Fabricate Portable Electron Source Based on Nitrogen Incorporated Ultrananocrystalline Diamond (N-UNCD)	• Prototype based on nitrogen incorporated ultrananocrystalline diamond film • Emission current densities of the order of 6mA/cm2 could be obtained at electric fields as low as 10 V/lm to 20V/lm	9,299,526, issued March 29, 2016	Yes	IN-14-019
Planer field emitters and high efficiency photocathodes based on ultrananocrystalline diamond	• Prototype planer filed emission based electron source for RF injectors in accelerators • At surface gradients 45–65 MV/m, peak currents of 1–80mA were achieved. • Good operation at moderate high vacuum (10^{-6} Torr)	9,418,814 issued Aug. 16, 2016	Yes	IN-14-106
Preparation of Carbon-Based Electrodes with High Thermal Conductivity for Battery Applications	• Unique combination of diamond nanoparticles and other carbon materials • Improves the ability to remove heat efficiently from the battery system	Prov. Patent App. No. 62/148,553 filed April 16, 2015; U.S. Patent App. No. 14/790,449 filed July 2, 2015	Yes	IN-13-078
Method to Fabricate Low-Stress N-UNCD Suitable for the Fabrication of MEMS/NEMS Devices	• Excellent chemical, mechanical and electrical properties, low intrinsic stress gradient • Could be applicable in many fields, including bio-medicine, optics, and sensors and MEMS actuators for space applications	6,475,690, issued October 25, 2016	Yes	IN-14-008
Fabrication of Robust, Harsh Environment Compatible MEMS/NEMS Actuators Based on Electrically Conducting Diamond Films	• Excellent chemical, mechanical and electrical properties, low intrinsic stress gradient • Could be applicable in many fields, including bio-medicine, optics, and sensors and actuators for space applications	(filed with ANL-IN-14-008, immediately above)	Yes	IN-14-009
Nitrogen Incorporated UltraNanoCrystalline Diamond As a Robust Electrical Contact to Diamond	• Efficient x-ray position detector for synchrotron applications	9,484,474, issued November 1, 2016; PCT application US14/40456 filed June 30, 2016	Yes	IN-12-098
Ultra-nano Crystalline Diamond Contacts for Diamond Electronic Devices	• Efficient x-ray position detector for synchrotron applications	15/339,295 filed October 31, 2016 (divisional of ANL-IN- 12-098 above)	Yes	IN-12-098B

Fabrication of P-N Junction Device Through Diamond/2D Materials Heterojunction	• Efficient, p-n junction diodes for power electronics and rectification applications	Patent app filed August 18, 2016		IN-15-097

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Argonne seeks a domestic entity to commercialize the above intellectual property. To learn more, please email partners@anl.gov to discuss your proposed commercialization plan.