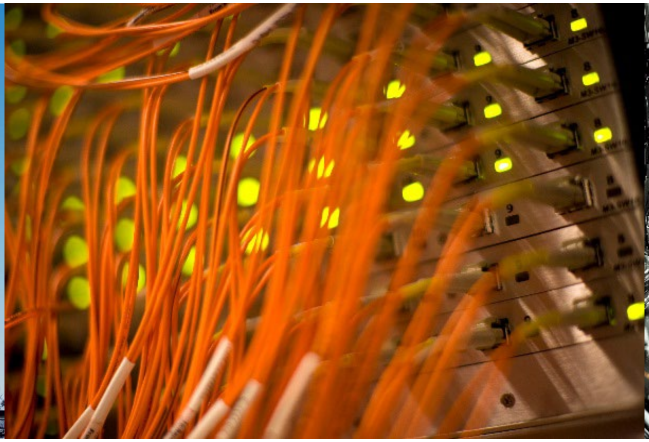
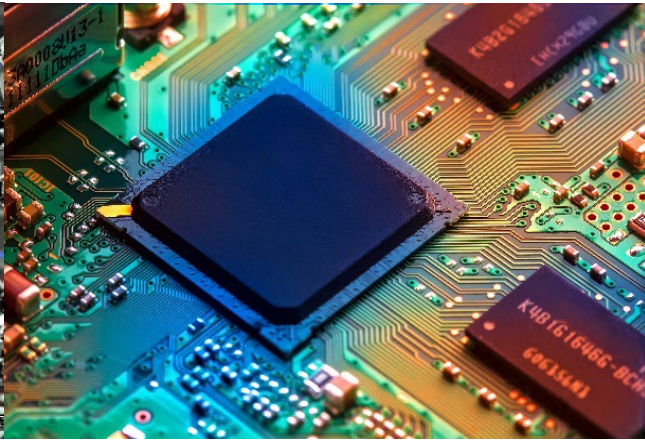
Diamond Power Semiconductor Devices

Mr. Hubert Elly, PhD Candidate
Mr. Keith Chang, PhD Candidate
Ms. Berre Vize, PhD Student

Coherent/II-VI Foundation 26th Mini-Conference,
Coherent Corporation Saxonburg, PA
May 13, 2026

PI: Prof. Can Bayram,
Professor, Intel Alumni Endowed Faculty Scholar
Department of Electrical and Computer Engineering,
University of Illinois at Urbana-Champaign, IL, USA
cbayram@illinois.edu
www.icorlab.ece.illinois.edu



ILLINOIS
Electrical & Computer Engineering
COLLEGE OF ENGINEERING

The Motivation: Climate Change

Typical climate change events: floods, heatwaves, drought, hurricanes, wildfires and loss of glacial ice.

Impact:

- 85% of the world's population & four-fifths of the world's land area affected today
- 216M - number of people who could migrate by 2050
- $7.9T - cost to the world economy by 2050

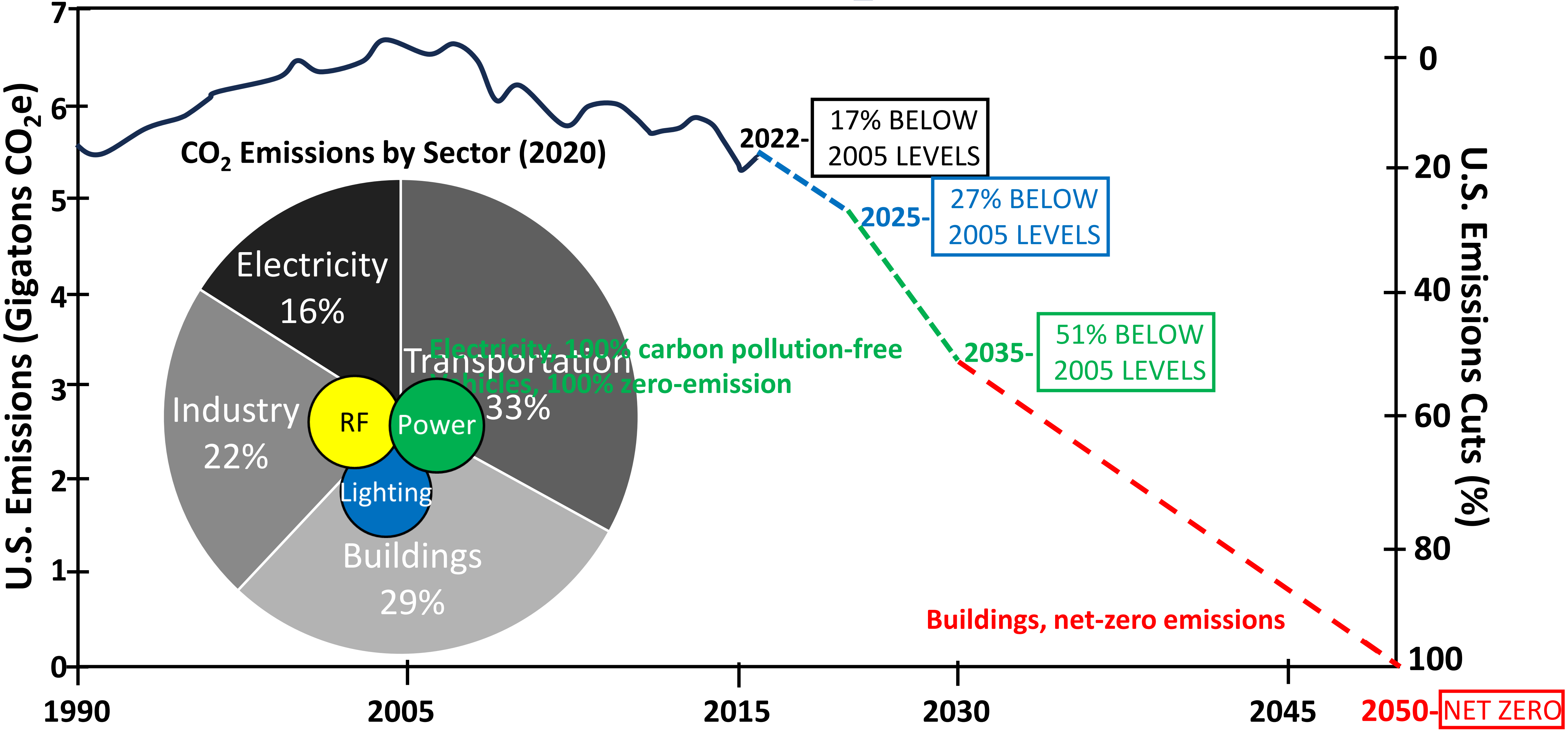
Impact:

- $26T - New economic benefits by 2030
- 65M - New low-carbon jobs created by 2030

- **Problem**:
  - Since the Industrial Revolution, global temperatures rose about 1°C (1.8 F) as the amount of carbon dioxide in the atmosphere has risen by about 40%.
- **Solution**:
  - Limit global temperature rise to 2°C (3.6 F) via setting a carbon budget of 1 trillion tonnes of carbon.
  - By 2050, be carbon neutral.

Image credit: NOAA; https://www.wri.org/climate; https://www.washingtonpost.com/climate-environment/2021/10/11/85-percent-population-climate-impacts/; https://www.un.org/en/climatechange/science/causes-effects-climate-change; https://climate.nasa.gov/effects/; https://www.ipcc.ch/sr15/faq/faq-chapter-4/

The Problem: CO_2 Emissions



Innovative COmpound semiconductoR LABoratory

Prof. Can Bayram; https://icorlab.ece.illinois.edu/

Lighting

Solid-state Lighting, Visible Light Emitting Diodes

Market is approximately $80B, CAGR > 15%

- Quadruple lighting efficiency
- Increase bulb lifetime by 30+ years

RF

Communication, 5G+, WBG HEMTs, MMIC

Market is approximately $1B, CAGR > 20%

- Increase data speeds by 100×
- Increase RF power density by 10×
- High temperature (>300°) operation

Power

WBG electronics, DC grids, bilateral grids

Market is approximately $0.5B, CAGR > 30%

- Cut losses by 90%
- An order smaller footprint

- Significant efficiency increase
- >50% bill of materials cost savings
- Up to 80% smaller system
- lower shipping, transportation, installation costs
- smaller installation crew as the system weighs less

Acknowledgements

The information, data, or work presented herein was funded in part by

- Office of Naval Research (ONR), under award number N00014-23-1-2423
- Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, ULTRAFAST Program award numbers DE-AR0001846 & DE-AR0001828.
- Coherent / II-VI Foundation
- Microelectronics Commons Program, a DoD initiative, under award number N00164-23-9-G062.
- ECE Illinois Intel Alumni Endowed Faculty Scholar Funds

We thank our other sponsors & collaborators

Schedule of Technical Tasks

Major Project Tasks	Year I				Year II				Year III			
Quarter #	1	2	3	4	1	2	3	4	1	2	3	4
Research Front #1. Physics & TCAD Simulations: Design diamond PCSS and SBDs for advanced power applications												
Task 1.a. Fundamental Study of Diamond Physics												
Task 1.b. PCSS Device Simulation												
Task 1.c. Schottky Barrier Diode Simulation												
Research Front #2. Micro-Fabrication: Fabricate high-performance diamond PCSS and SBDs												
Task 2.a. Electronic-grade growth and characterization.												
Task 2.b. Lateral PCSS fabrication												
Task 2.c. Vertical PCSS fabrication												
Task 2.d. Hybrid PCSS fabrication												
Task 2.e. Schottky barrier diode fabrication												
Research Front #3. Device Characterization and Analysis: Advanced characterization of fabricated diamond PCSS and SBDs												
Task 3.a. (PCSS) Optical and Electrical Setup												
Task 3.b. (SBD) Schottky diode breakdown characterization												

Program Accomplishments

2 Alumni

(Ph.D. in EE) Jaekwon Lee, Distinguished Postdoctoral Fellow, Stanford University, CA, USA.

(Ph.D. in EE) Zhuoran Han, Display Technology Engineer, Apple, CA, USA.

3 Current Performers

(Expected graduation in May 2027) Hubert Elly, PhD candidate in ECE Illinois.

(Expected graduation in May 2027) Keith Chang, PhD candidate in ECE Illinois.

(Expected graduation in May 2028) Berre Vize, PhD student in ECE Illinois.

NDSEG
NATIONAL DEFENSE SCIENCE & ENGINEERING GRADUATE FELLOWSHIP

Program Accomplishments (cont'd)

4 Journal Papers

1. **H. Elly**, E. Cheng, A. Mazumder, **Z. Han**, **J. Lee**, A. Mironov, and **C. Bayram**, "Ultrafast vertical photoconductive intrinsic diamond switch with high current (17.1 A at 1 kV)," Appl. Phys. Lett. 128 (12),123301 (2026)
2. **Z. Han**, **J. Lee**, A. Mazumder, **H. Elly**, S. Messing, A. Mironov, and **C. Bayram**, "Record performance in intrinsic, impurity-free lateral diamond photoconductive semiconductor switches," Appl. Phys. Lett. 126 (15), 152105 (2025)
3. **J. Lee**, **C. Bayram**, and J.-P. Leburton, "Non-linear Transport in (Ultra) Wide Bandgap Semiconductors: Diamond Versus Cubic GaN," IEEE Trans. Electron Devices 71 (9), 5638-5644 (2024) **(TOP Downloaded Article)**
4. **Z. Han**, **J. Lee**, S. Messing, T. Reboli, A. Mironov, and **C. Bayram**, "High Current Density Diamond Photoconductive Semiconductor Switches with a Buried, Metallic Conductive Channel," IEEE Electron Device Lett. 45 (6), 1044 (2024) **(TOP Downloaded Article)**

3 Patents

1. **J. Lee**, **Z. Han**, **C. Bayram** BURIED CHANNEL PHOTOCONDUCTIVE SWITCH (U.S. National Stage Patent Application No.: 19/502,606)
2. **J. Lee**, **Z. Han**, A. Mironov, **C. Bayram** LIGHT-TRIGGERED DIAMOND SWITCHES (U.S. National Stage Patent Application No.: 19/502,572)
3. **Z. Han**, **C. Bayram** BIDIRECTIONAL DIAMOND DEVICES (U.S. Patent Application No.: 63/609,000)

Program Accomplishments (cont'd)

10 Presentations

1. **H. Elly**, **K. Chang**, S. Deng, R. Chakraborty, E. Cheng, J.P. Leburton, A. Mironov, F. Luo, **C. Bayram**, "Diamond Photoconductive Semiconductor Switches," 2026 ARPA-E Energy Innovation Summit, San Diego, CA, 2026
2. **H. Elly**, **Z. Han**. **J. Lee**, A. Mazumder, S. Messing, A. Mironov, **C. Bayram**, "Diamond Photoconductive Semiconductor Switches for the Next Generation Power Grid," 2025 Holonyak Workshop, Champaign, IL, 2025
3. **K. Chang**, "Cubic GaN and Diamond: Emerging Semiconductors for Advanced Optoelectronics and Power Electronics," Cardiff University, Cardiff, UK, 2025
4. **K. Chang**, "Diamond p-Type Lateral Schottky Barrier Diodes with High Breakdown Voltage (>4.6 kV)," ICNS-15, Malmo, Sweden, 2025
5. **J. Lee**, **Z. Han**, **H. Elly**, A. Mazumder, S. Deng, **K. Chang**, J.P. Leburton, A. Mironov, F. Luo, **C. Bayram**, "Diamond Photoconductive Semiconductor Switches," 2025 ARPA-E Energy Innovation Summit, Washington, D.C., 2025
6. **Z. Han**, **J. Lee**, S. Messing, T. Reboli, A. Mironov, and **C. Bayram**, "High Current Density Diamond Photoconductive Semiconductor Switches with a Buried, Metallic Conductive Channel," 2024 Materials Research Society Fall meeting, Boston, MA, 2024
7. **Z. Han**, **J. Lee**, and **C. Bayram**, "Diamond Power Semiconductor Devices," 24th Coherent/II-VI Foundation Mini-conference, Virtual, 2024
8. **Z. Han**, and **C. Bayram**, "Diamond p-Type Lateral Schottky Barrier Diodes with High Breakdown Voltage (4612 V at 0.01 mA/mm)", 2024 Materials Research Society Fall meeting, Boston, MA, 2024
9. A. Mazumder, **Z. Han**, **J. Lee**, S. Messing, T.O. Reboli, A.E. Mironov, and **C. Bayram**, "Ultrafast Diamond Photoconductive Switches for High Voltage Power Grid Protection," Siegman International School on Lasers, Optica W-4 (2024).
10. **Z. Han**, **J. Lee,** and **C. Bayram**, "Buried Channel Diamond Photoconductive Semiconductor Switches," 2023 Lester Eastman Conference on High Performance Devices, Chicago, IL, USA, 2023

Program Accomplishments (cont'd)

2 Faculty Awards

1. Prof. Bayram promoted to Full Professor
2. Prof. Bayram elevated to SPIE Fellow status

10 Student Awards

1. Hubert received the Nick and Katherine Holonyak, Jr. Graduate Student Award
2. Keith selected as a 2026 National Defense Science and Engineering Graduate (NDSEG) Fellow
3. Jaekwon awarded a Graduate College Conference Travel Grant
4. Jaekwon selected as 2025-2028 Stanford Distinguished Energy Postdoctoral Fellow
5. The Graduate Runner-up (i.e., 2nd place – the highest campus recognition in the event history), 2024 National Inventors Hall of Fame Collegiate Inventors Competition, Z. Han and J. Lee
6. Jaekwon selected as a Mavis Future Faculty Fellow
7. Jaekwon awarded an SPIE Optics and Photonics Education Scholarship in the amount of $3,500
8. Jaekwon awarded a Siegman School on Lasers Grant
9. Jaekwon invited to attend Siegman School on Lasers, hosted by the Stanford University, U.S.A
10. Jaekwon received ECE Illinois Nick and Katherine Holonyak, Jr. Outstanding Research Award

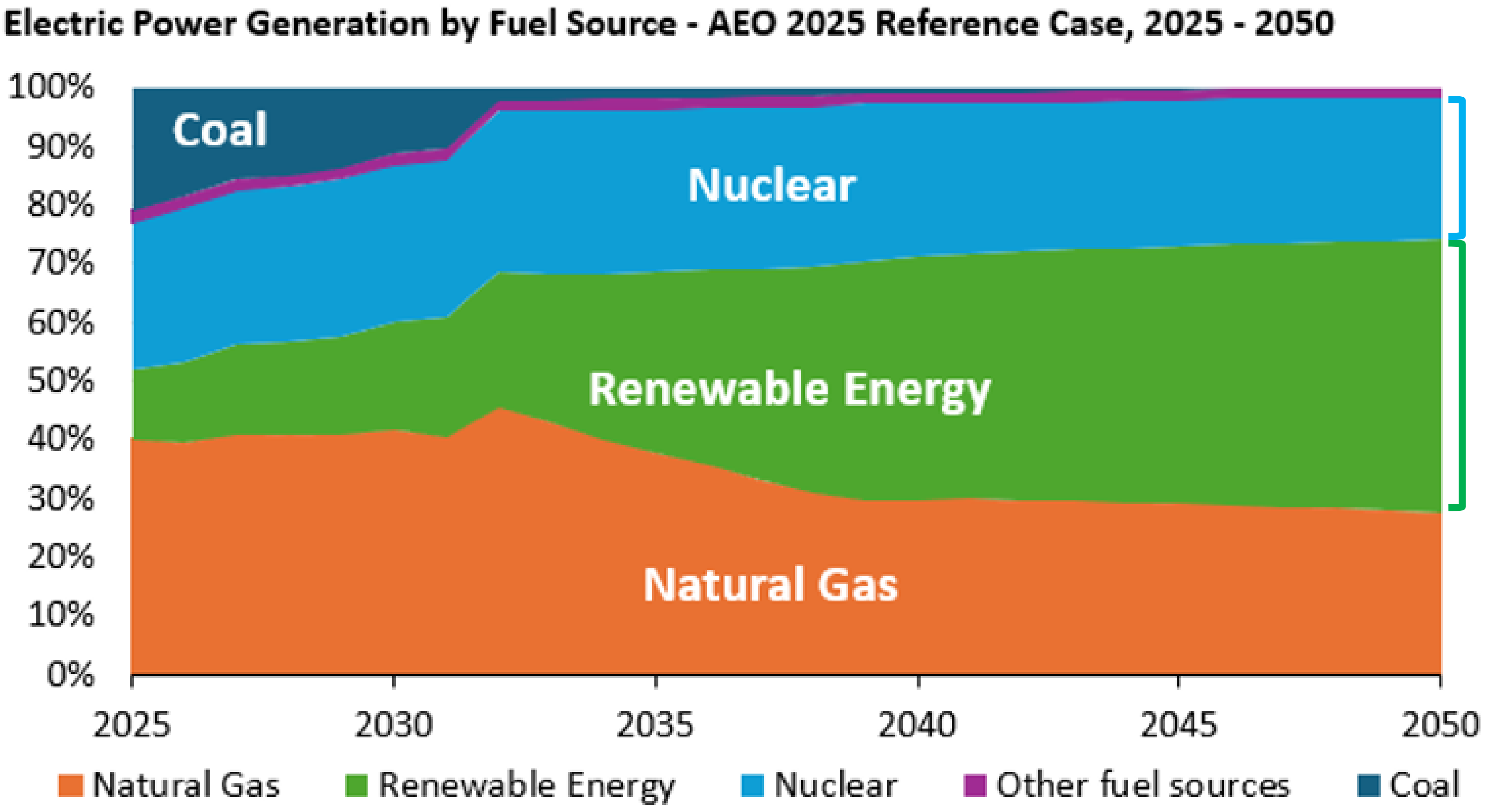
4 News

1. US team reports diamond power switch that shatters performance records, https://compoundsemiconductor.net/article/123837/Diamond_power_switch_shatters_performance_records, March 23, 2026
2. Student Teams' Innovations Win 2024 Collegiate Inventors Competition, https://www.invent.org/news/cic/2024/winners, October 18, 2024
3. US team discovers 'hidden carrier' cooling in Ⅲ-Nitrides, https://compoundsemiconductor.net/article/119798/US_team_discovers_and_hidden_carrierand__cooling_in_III-nitrides, July 16, 2024
4. US team reinvents the photoconductive switch, https://compoundsemiconductor.net/article/119149/US_team_reinvents_the_photoconductive_switch, April 11, 2024.

Outline

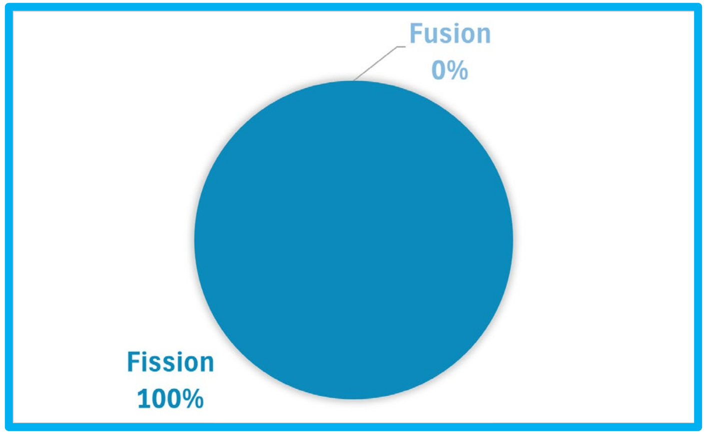
1. **Motivation**
    - Renewable Energy Revolution
    - Ultrafast Megawatt Solid-State Electronics
    - Diamond Power Devices
2. **Diamond PCSS**
    - Photoconductivity: Road to Ultrafast Megawatt Switching
    - Intrinsic Diamond PCSS
    - Vertical Diamond PCSS
    - Hybrid Lateral-Vertical PCSS
3. **Future Work**
    - Advanced Edge Termination Techniques for Diamond Schottky Contacts

Motivation: Renewable Energy Revolution

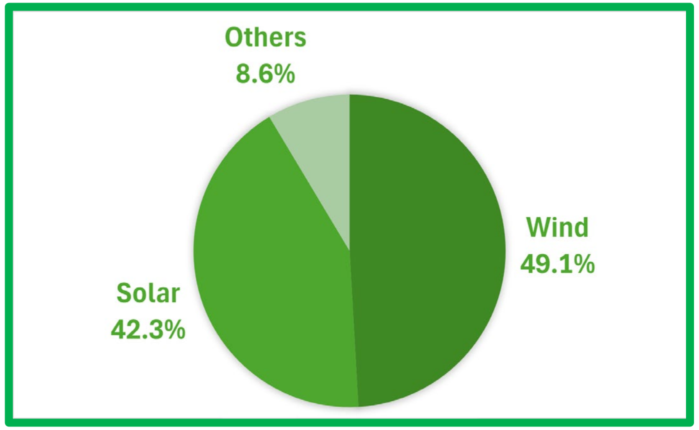


U.S. Energy Information Administration, Annual Energy Outlook, 2025

Projected 2050 Nuclear Energy Mix



Projected 2050 Renewable Energy Mix



Motivation: Renewable Energy Revolution

Goal: accelerate renewable and carbon-free energy expansion

Approach:
Efficient Power Transmission

Approach:
Novel Energy Sources

Megawatt-Class
Ultrafast Switching

Motivation: HVDC Circuit Breakers

Offshore Wind Farm

HVDC Submarine Cable

>500 miles

(1 MV/10 GW)

Solar Farm

HVDC Overhead Cable

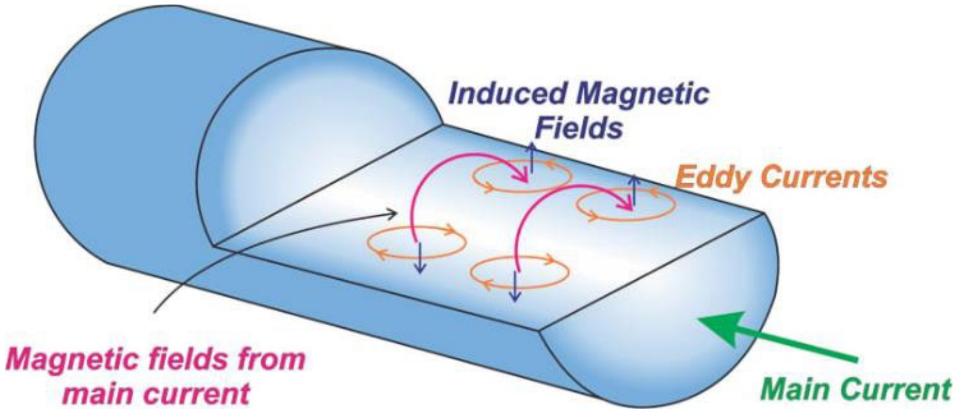
Urban Area

Offshore wind farm: https://upload.wikimedia.org/wikipedia/commons/thumb/7/72/Block_Island_offshore_wind_farm_P6290638m.jpg/3840px-Block_Island_offshore_wind_farm_P6290638m.jpg
Solar farm: https://upload.wikimedia.org/wikipedia/commons/f/f5/02-09-15_First_Solar_Desert_Sunlight_Solar_Farm_%2815863210084%29.jpg
Submarine cable: https://acacia-inc.com/wp-content/uploads/2024/05/Submarine-Cable-Networks.jpg
HVDC overhead cable: https://encrypted-tbn2.gstatic.com/images?q=tbn:ANd9GcTFuNqHLzDOMNHsM1BYVmOAiEkr9yKikLkxnRknkcq4Gcld81wE
Urban area: https://upload.wikimedia.org/wikipedia/commons/thumb/0/01/New_York_City_(New_York,_USA),_Empire_State_Building_--_2012_--_6448.jpg/3840px-New_York_City_(New_York,_USA),_Empire_State_Building_--_2012_--_6448.jpg?utm_source=commons.wikimedia.org&utm_campaign=index&utm_content=thumbnail

Motivation: HVDC Circuit Breakers

HVDC Advantages: Loss Reduction

- ❖ Reduces skin effect, dielectric loss, and reactive power loss
- ❖ Offers 50% reduction in losses compared to traditional HVAC at long distances (>100 miles)



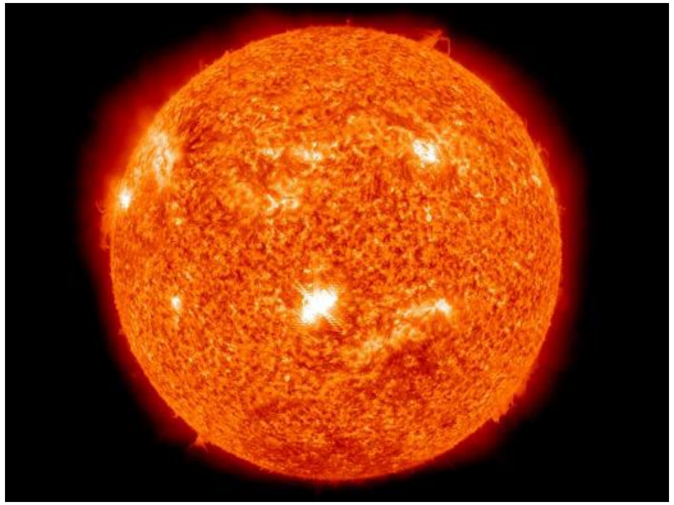
HVDC Challenge: Circuit Breaking

- ❖ No natural zero-crossing in DC signal for rapid arc extinguishment
- ❖ Extreme stress (10s of kV) and rapid current spikes (100s of A)
- ❖ Traditional (HVAC) electromechanical circuit breakers too slow (> 1 ms)

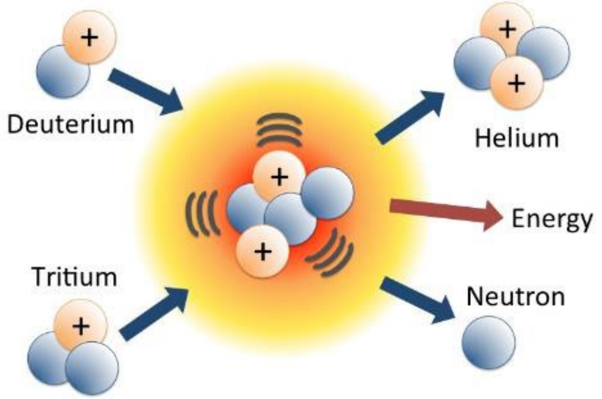
Skin Effect: https://www.allaboutcircuits.com/technical-articles/understanding-the-skin-effect-cylindrical-and-rectangular-conductors-eddy-currents-and-current-crowding/
HVAC circuit breaker: https://upload.wikimedia.org/wikipedia/commons/6/68/Circuit_breakers_at_substation_near_Denver_International_Airport,_Colorado.jpg

Motivation: Pulsed Power for Nuclear Fusion

Superheated Plasma

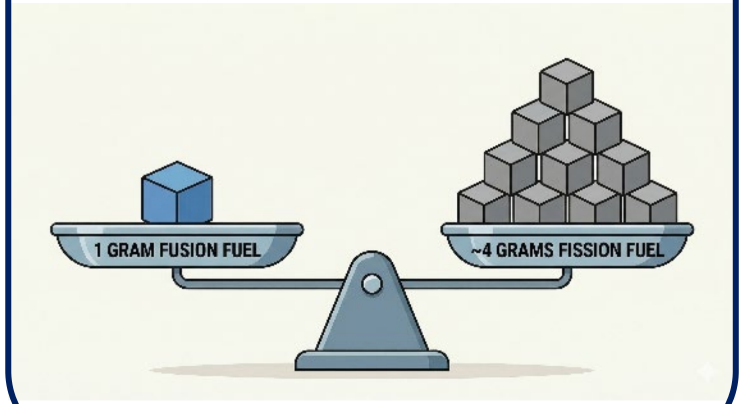


Fusion Reaction



Fusion Power

- ✓ “Infinite” fuel source
- ✓ No radioactive/carbon waste
- ✓ Highest energy density

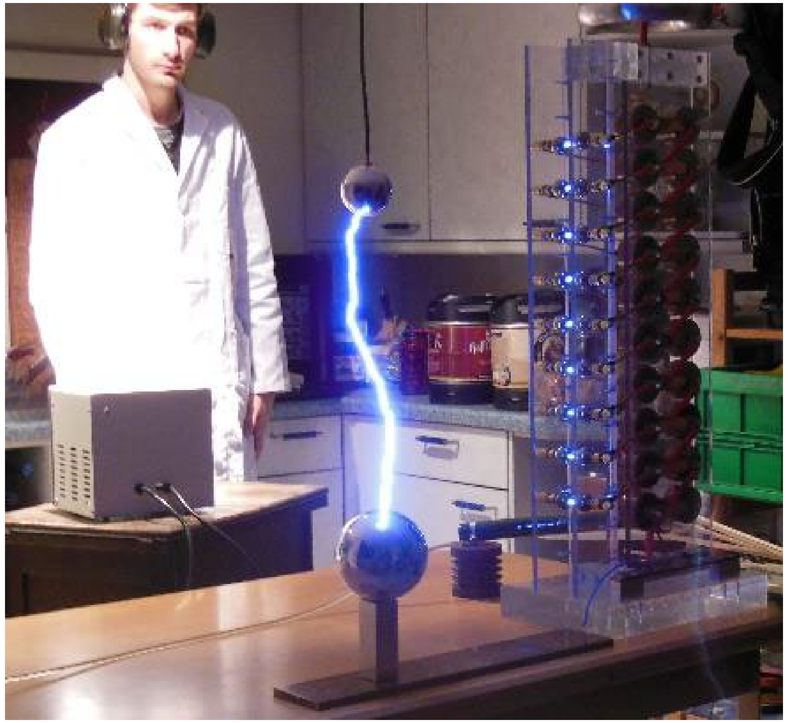


Sun: https://images.nationalgeographic.org/image/upload/t_RL2_search_thumb/v1638882786/EducationHub/photos/sun-blasts-a-m66-flare.jpg
DT fusion reaction: https://nuclear-power.com/wp-content/uploads/2014/11/nuclear_fusion.jpg

Motivation: Pulsed Power for Nuclear Fusion

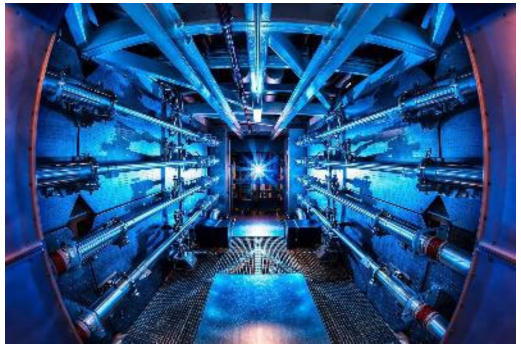
Pulsed Power

- Generates ultrahigh voltage (1 MV) pulses



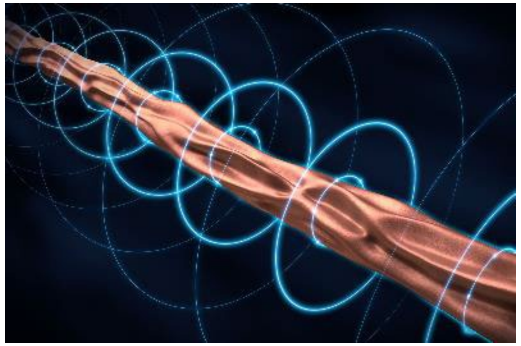
Laser Inertial Confinement Fusion

- Massive electron beams to pump excimers lasers to achieve MJ output for heating plasmas



Z-pinch Inertial Confinement Fusion

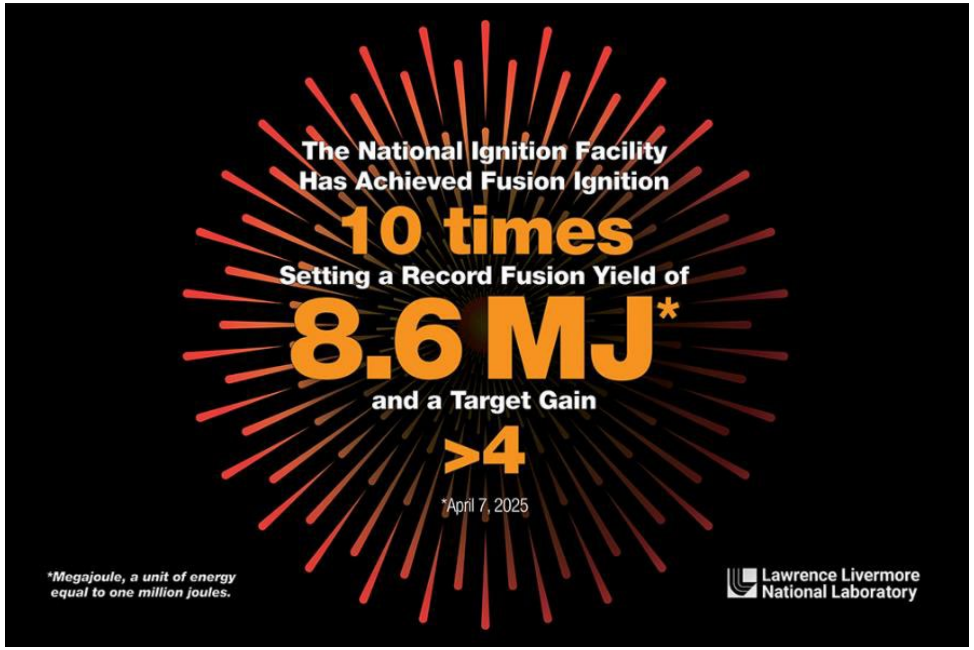
- Massive $\frac{dI}{dt}$ to create a large magnetic field to compress plasma and achieve fusion conditions



Marx generator: https://upload.wikimedia.org/wikipedia/commons/3/39/Marxgeneratorfz.JPG
ICF Laser: https://www.energy.gov/sites/default/files/styles/full_article_width/public/2023-12/2012-037864-lg_0.jpg?itok=5I3bVFbl
Z-pinch fusion: https://cdn.prod.website-files.com/6500cc19ec1dfde111607ce2/6500cc19ec1dfde111608142_640784f34736b000450e7231_History-Zpinch-lead.jpg

Motivation: Pulsed Power for Nuclear Fusion

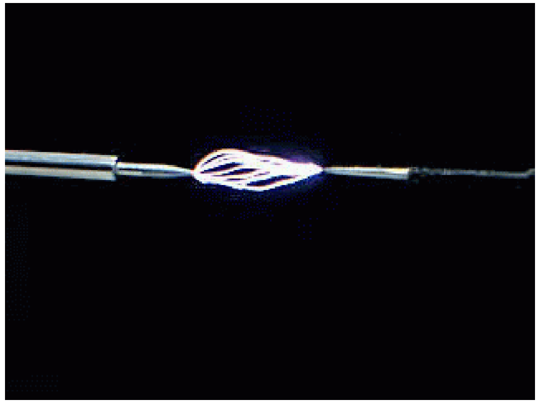
Fusion Breakthrough



Fusion Challenge: Pulsed Power

- ❖ Rely on spark gap switches due to high voltage requirement
- ❖ Bulky, unreliable, low repetition rate, low slew-rates

Fusion pulsed power system



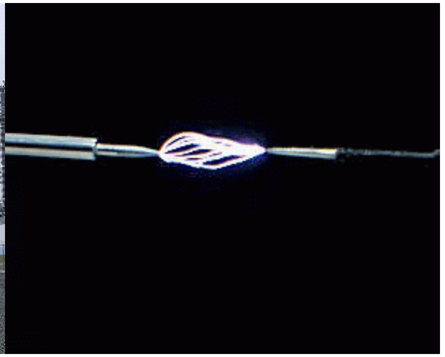
Spark gap switch

Fusion pulsed power system: https://www.hst.tu-darmstadt.de/media/hst/laborausstattung/stossspannung/marx_02.jpg
Spark gap switch: https://upload.wikimedia.org/wikipedia/commons/7/71/%D0%98%D1%81%D0%BA%D1%80%D0%BE%D0%B2%D0%BE%D0%B9_%D1%80%D0%B0%D0%B7%D1%80%D1%8F%D0%B4.gif

Motivation: Ultrafast Megawatt Switching Challenge

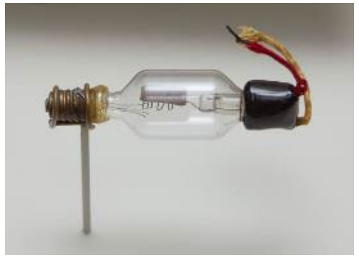
Modern Megawatt Switches

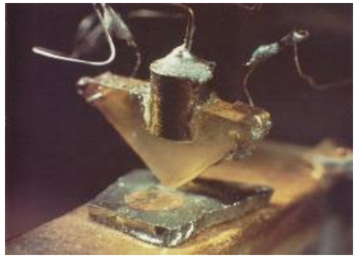
- ❖ Electromechanical and spark gap switches
- ❖ Slow, bulky, and unreliable



Megawatt Solid-State Switches

- ✓ Ultrafast switching (< 1 μs)
- ✓ Compact footprint
- ✓ Energy efficient
- ✓ Higher reliability





Another solid-state revolution?

HVAC circuit breaker: https://upload.wikimedia.org/wikipedia/commons/6/68/Circuit_breakers_at_substation_near_Denver_International_Airport,_Colorado.jpg
Spark gap switch: https://upload.wikimedia.org/wikipedia/commons/7/71/%D0%98%D1%81%D0%BA%D1%80%D0%BE%D0%B2%D0%BE%D0%B9_%D1%80%D0%B0%D0%B7%D1%80%D1%8F%D0%B4.gif
Vacuum tube amplifier: https://upload.wikimedia.org/wikipedia/commons/1/14/Triode_tube_1906.jpg
Point contact transistor: https://www.allaboutcircuits.com/uploads/articles/smithsonianchips_pointcontacttransistor.jpg

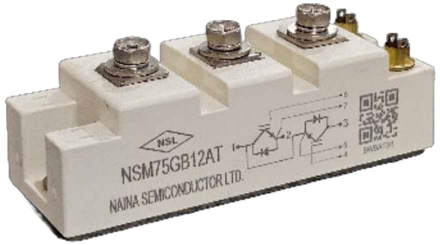
Motivation: Modern Power Semiconductor Devices

Higher Voltage Handling ← → *Higher Speed*

Si Power Devices

Thyristor
- Voltage: 9.5 kV
- Switching: < 1 kHz

IGBT
- Voltage: 6.5 kV
- Switching: <100 kHz



MOSFET
- Voltage: 1.5 kV
- Switching: 20 MHz

IMPATT Diode
- Voltage: 100 V
- Switching: >100 GHz

Insufficient Power Handling and Speed for heavy duty applications in HVDC grid and fusion systems!

Thyristor: https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcTliNZb9fC59Krcc0qrOJ5pVixN_mCgU9UF9zuCbaZOrL7fgfKv
IGBT: https://nainasemi.com/public/admin/assets/images/product/1748599284.png
Power MOSFET: https://americas.fujielectric.com/wp-content/uploads/2021/08/MOSFETs.png
IMPATT diode: https://terasense.com/wp-content/uploads/2017/10/8_67tygfv.jpg

Motivation: Diamond Power Semiconductor Devices

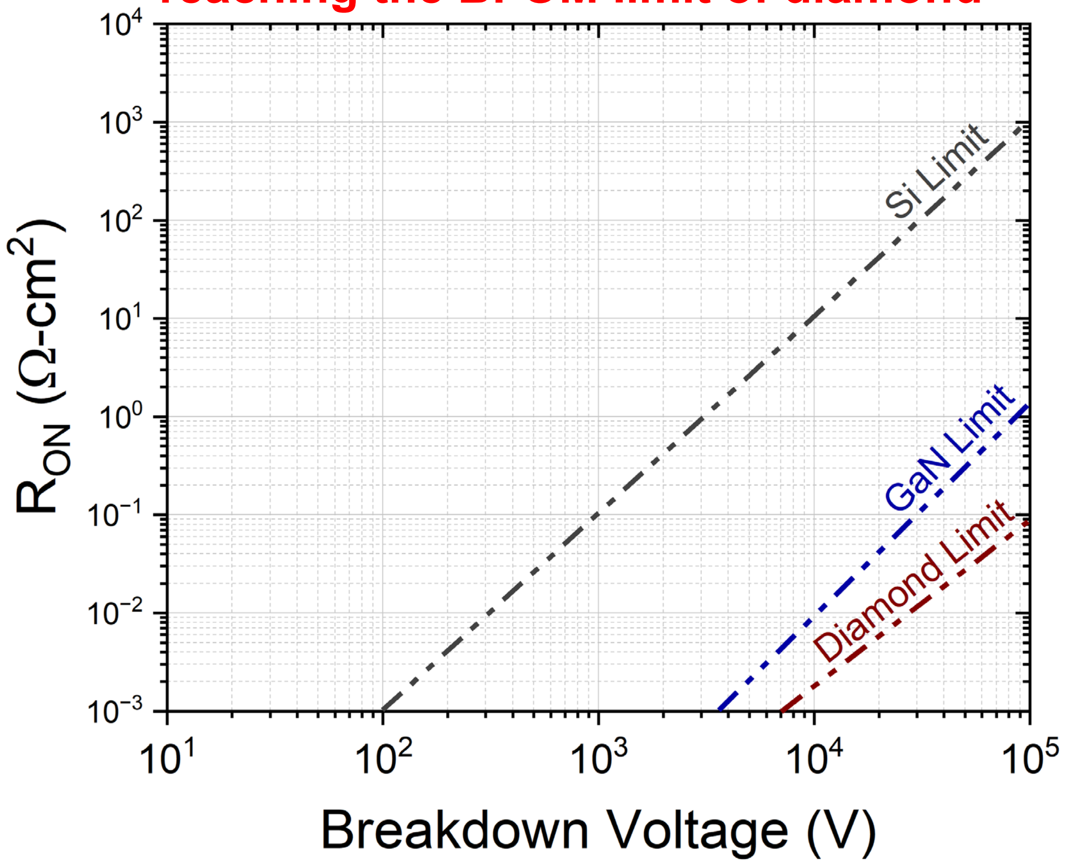
Solution: (Ultra) Wide Bandgap Materials

Property		Si	4H-SiC	GaN	β-Ga_2O_3	AlN	Diamond
Bandgap(eV)		1.1	3.3	3.4	4.9	6.1	5.5
Breakdown field (MV/cm)		0.3	2.8	3.5	8	10	7.7-20
Relative permittivity (a.u.)		11.8	9.8	9	9.9	8.5	5.5
RT mobility (cm^2/V-s)	electron	1500	1000	>1000 (bulk)	300	300	1060
	hole	480	120	<200 (bulk)	-	14	2100 (bulk)
Thermal conductivity (W/cm-K)		1.5	3.7	1 (on Si) 1.65 (on sapphire) 2.53 (on GaN)	0.11-0.27	2.53-3.19	22
Saturation velocity ($x10^7$cm/s)	electron	1	1.9	2.5	2	1.4	2.5
	hole	0.8	1.2	-	-	-	1.4

Donato, N., et al. “Diamond Power Devices: State of the Art, Modelling, Figures of Merit and Future Perspective.” Journal of Physics., vol. 53, no. 9, 2020

Motivation: Diamond Power Devices Challenges

Diamond devices are still far from reaching the BFOM limit of diamond



Benchmarking of diamond power devices

- Difficult to dope due to tight lattice
- Limited dopant choices
  - B for p-type
  - P for n-type
- High dopant activation energy
  - 0.38 eV for B
  - 0.57 eV for P

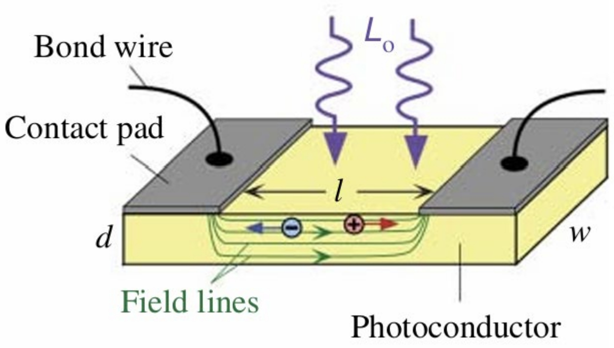
M. W. Geis *et al.*, "Progress toward diamond Power Field-Effect transistors," *Physica Status Solidi A-applications and Materials Science*, vol. 215, no. 22, p. 1800681, Nov. 2018.

Diamond PCSS: Motivation

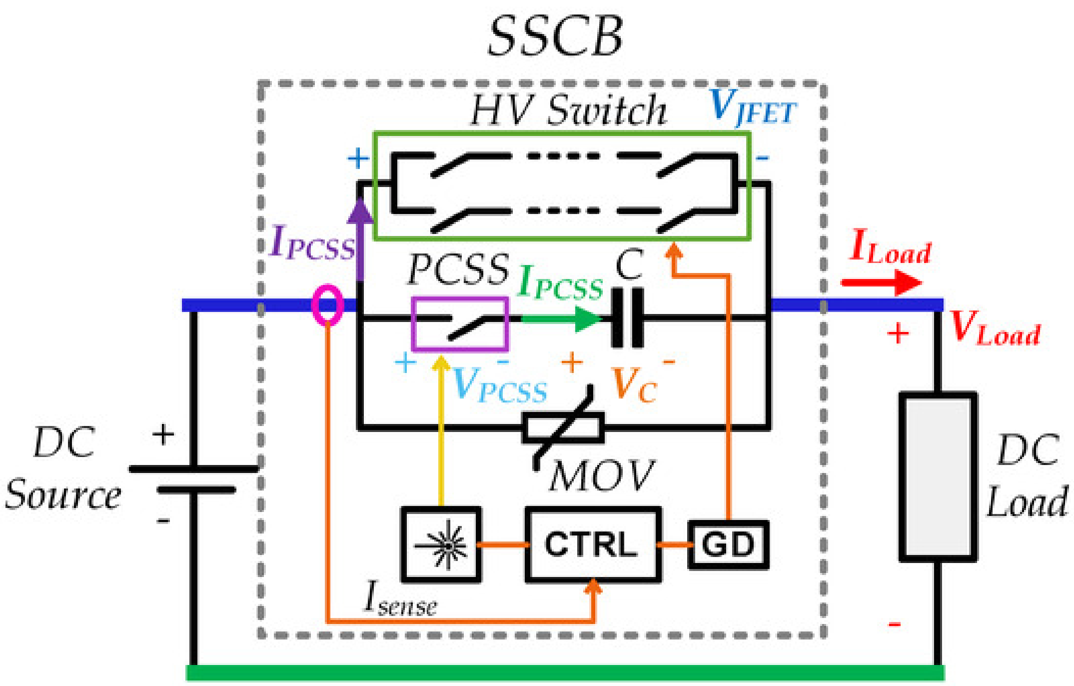
How do we leverage the full potential of diamond?

Solution: Photoconductivity

- ✓ Ultrafast carrier generation via optical generation
- ✓ Ambipolar conduction
- ✓ Conductivity modulation without the need for impurities



PCSS in solid-state HVDC circuit breaker

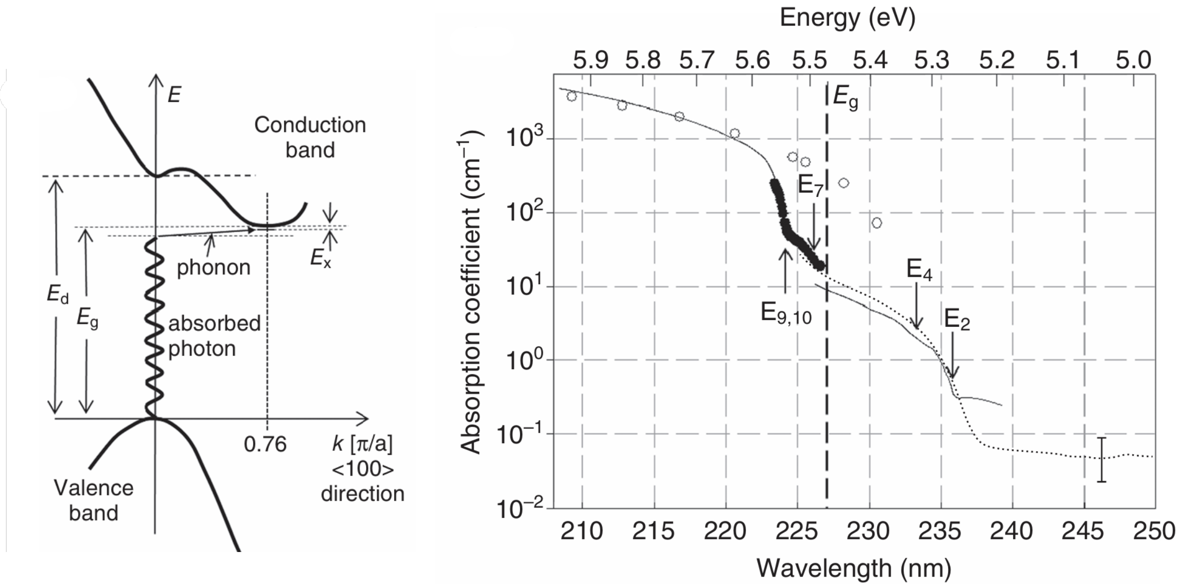


>20 kV and >250 A Operation Required

*V. Meyers et al., “Photoconductive Semiconductor Switches: Materials, Physics, and Applications,” Appl. Sci., vol. 15, no. 2, p. 645, Jan. 2025, doi: 10.3390/app15020645.
*S.O. Kasap, “Photoconductivity: Fundamental Concepts,” in Photoconductivity and Photoconductive Materials,“ (John Wiley & Sons, Ltd, 2022), pp. 1–88

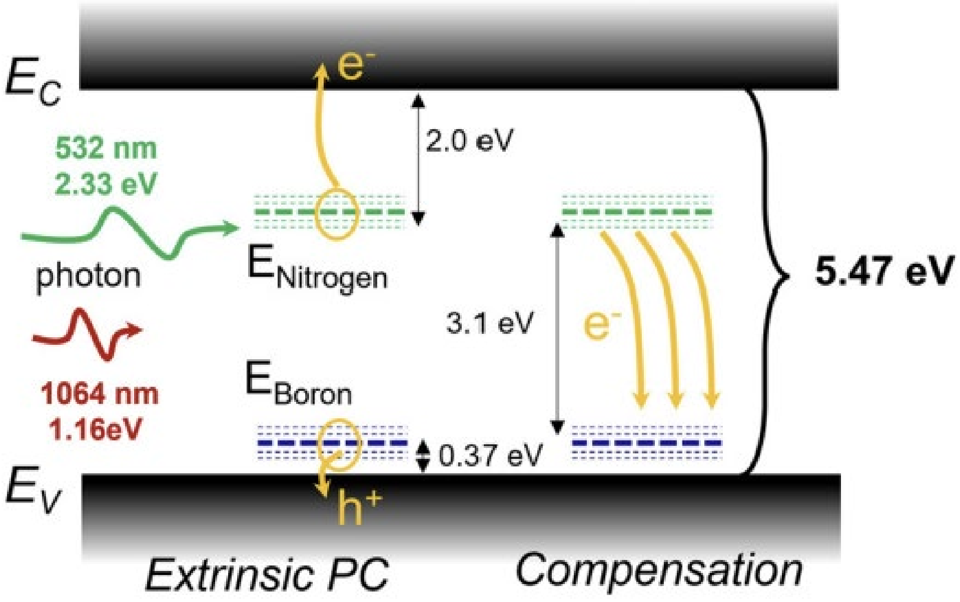
Diamond PCSS: Photoconductivity in Diamond

Optical Absorption in Intrinsic Diamond



- 5.47 eV indirect bandgap → λ = 226.7 nm
- Phonon absorption > 227 nm and emission < 227 nm
- Useful laser wavelength range: < 235 nm

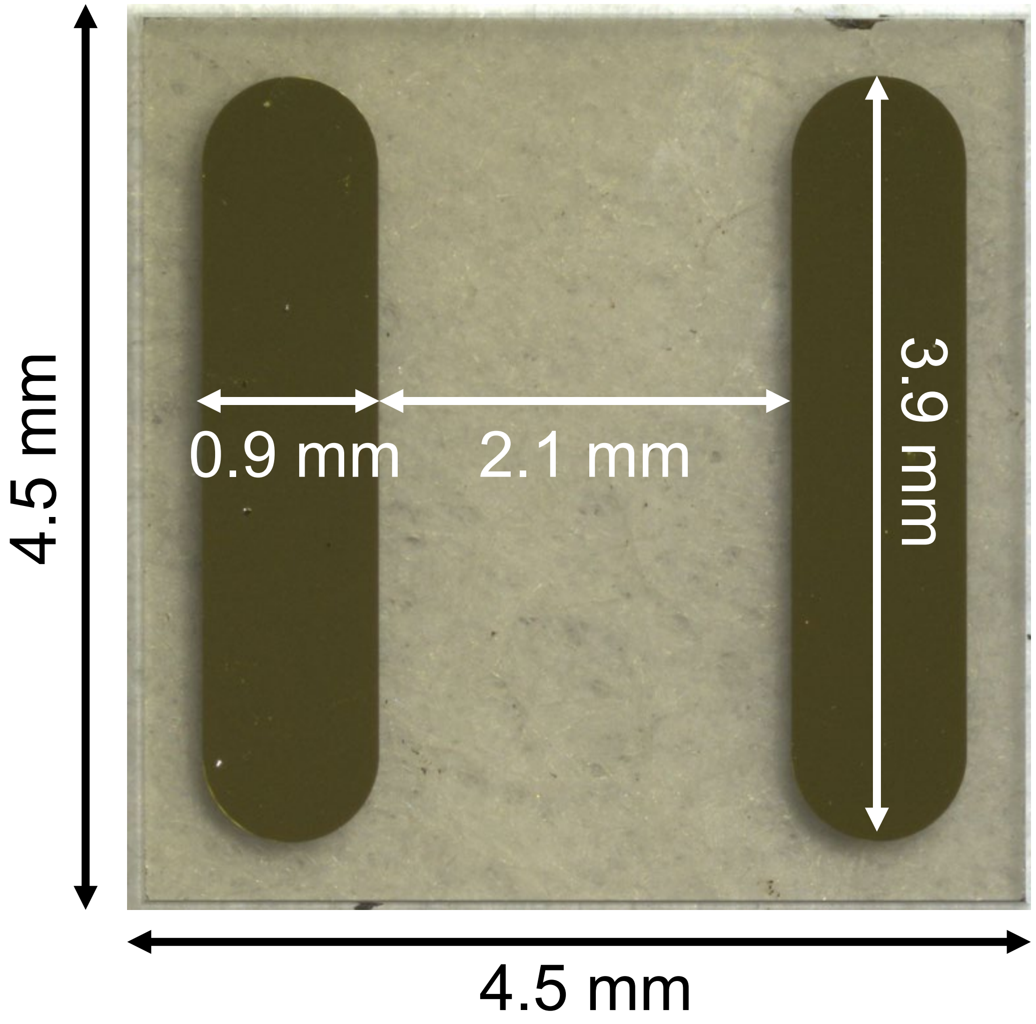
Photocarrier Generation in Diamond



- Intrinsic excitation: bandgap excitation
  - Large photocurrent response
- Extrinsic excitation: impurity activation
  - Cheap optical trigger sources

R.P. Mildren, “Intrinsic Optical Properties of Diamond,” in Optical Engineering of Diamond, (John Wiley & Sons, Ltd, 2013), pp. 1–34.

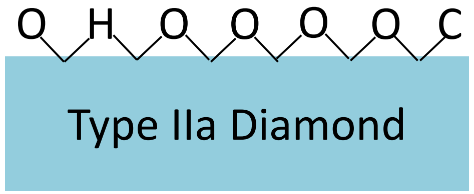
Intrinsic Diamond PCSS: Device Structure



Secondary Ion Mass Spectroscopy (SIMS) Results

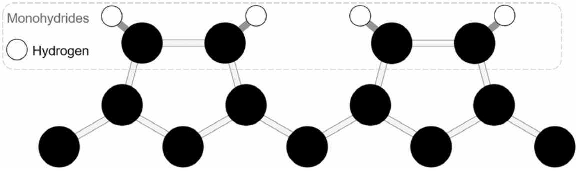
Substrate Type	[B] (cm^{-3})	[N] (cm^{-3})
CVD IIa	$< 1.0 \times 10^{14}$	$< 3.0 \times 10^{15}$

Intrinsic Diamond PCSS: Device Fabrication

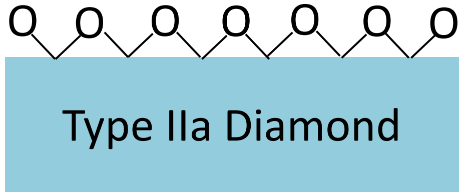


Sample preparation

- HPHT or CVD diamond substrate

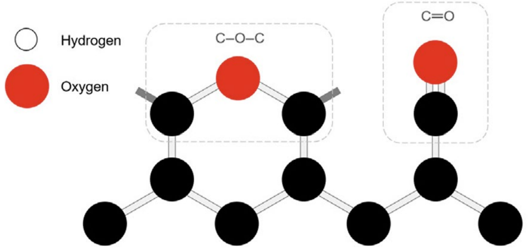


H-terminated diamond (100) surface

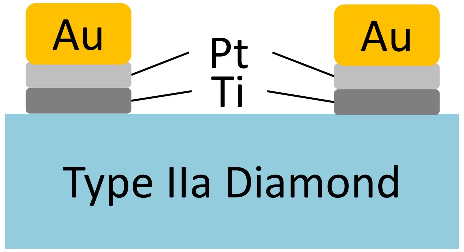


Oxygen termination

- RCA clean
- Boiling $H_2SO_4/HNO_3/HClO_4$ bath

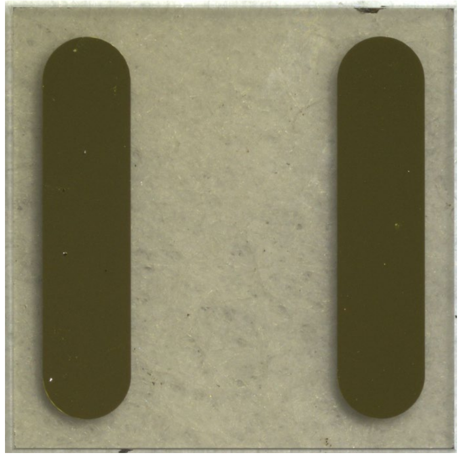


O-terminated diamond (100) surface

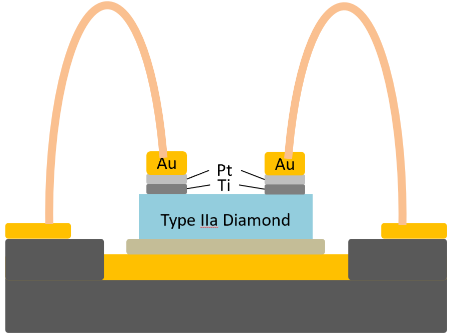


Contact deposition

- Photolithography
- E-beam evaporation
- Liftoff
- Anneal

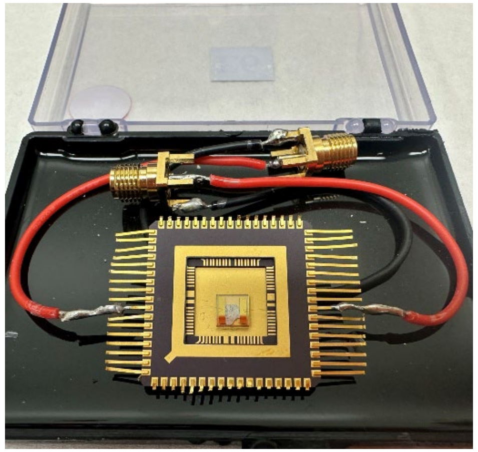


Fabricated PCSS



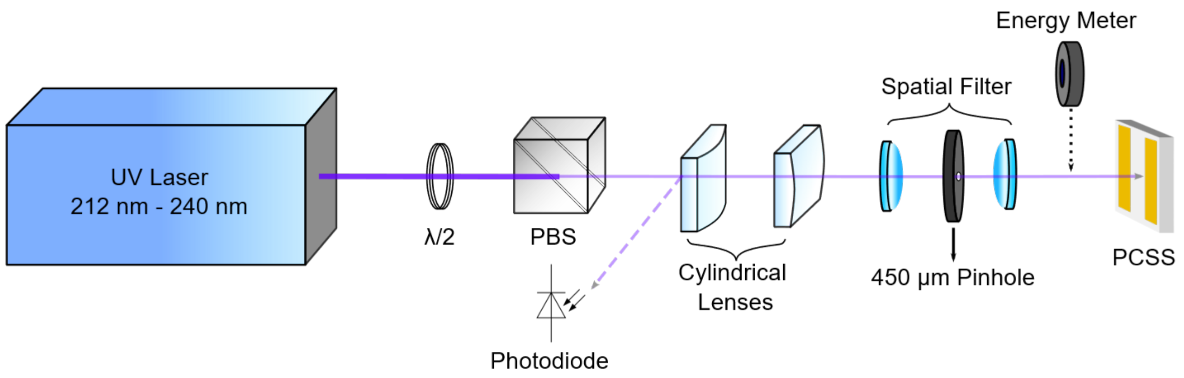
Packaging

- Packaging on chip carrier
- Ball-bonding



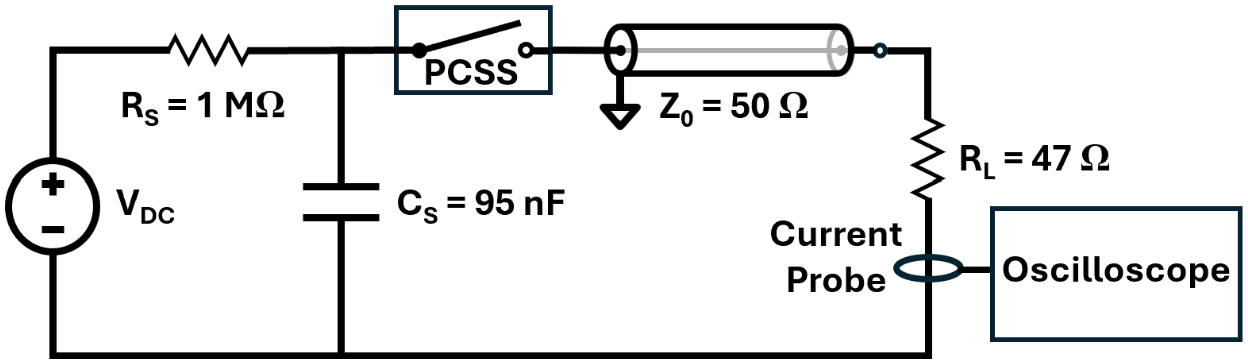
PCSS Packaged

Intrinsic Diamond PCSS: Characterization



PCSS Optical Triggering Setup

- ❖ OPO: optical parametric oscillator
- ❖ λ/2: half-wave plate
- ❖ PBS: polarizing beam splitter

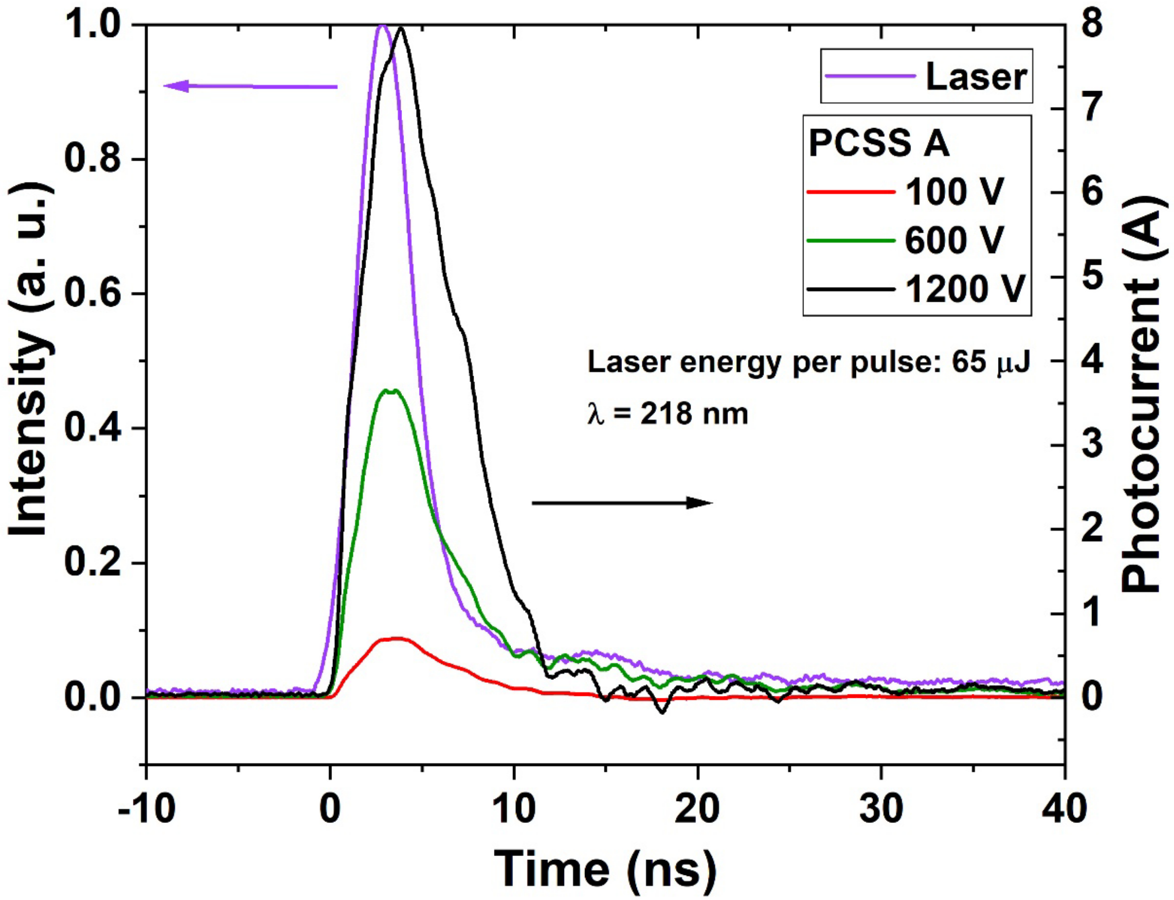


PCSS Electrical Measurement Setup

- ❖ Input filter stabilizes voltage at the PCSS
- ❖ SMA connections for noise reduction
- ❖ Current probe for closed loop measurement

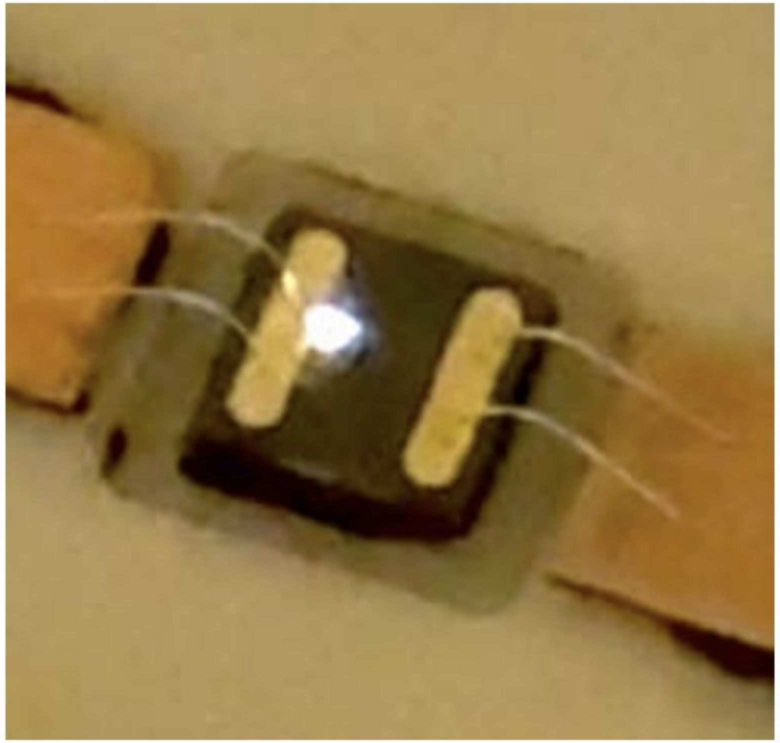
*Courtesy of Professor J. Gary Eden and the Laboratory for Optical Physics and Engineering (University of Illinois)

Intrinsic Diamond PCSS: Results



- ❖ **Laser condition:** 218 nm with 65 μJ, 4 ns pulse width, and 10 Hz repetition rate
- ❖ **8.0 A achieved at 1.2 kV bias**

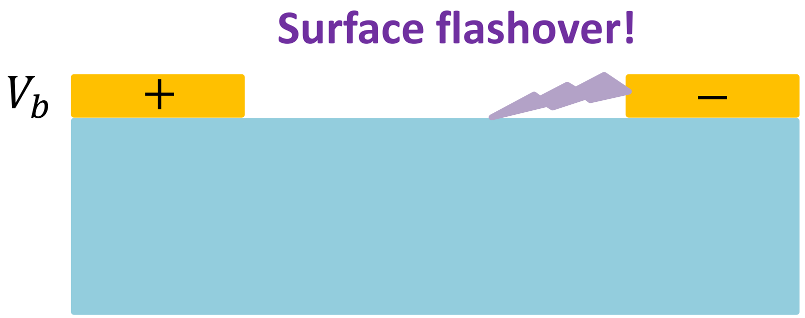
Intrinsic Diamond PCSS: High Voltage Challenge



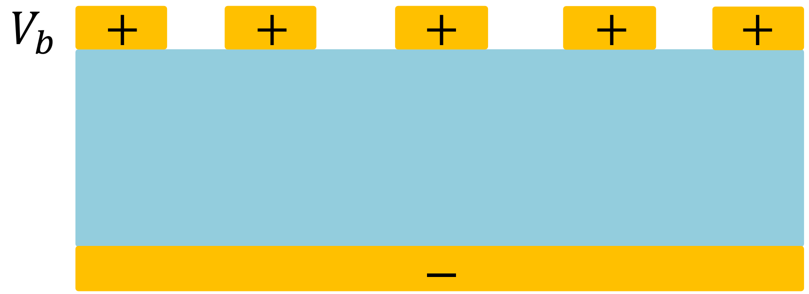
- Device prematurely failed at 9 kV, falling short of the 20 kV target for HVDC circuit breaker application
- Failure attributed to **surface flashover**, an inherent problem for **lateral** devices

Vertical Diamond PCSS: Motivation

Lateral PCSS



Vertical PCSS

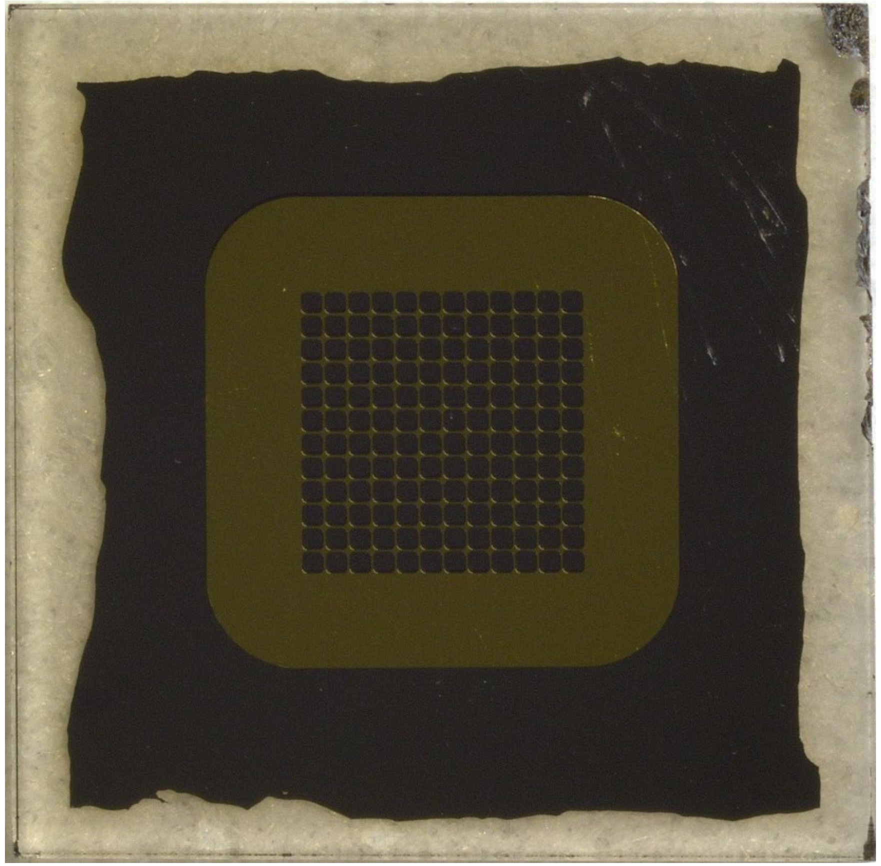


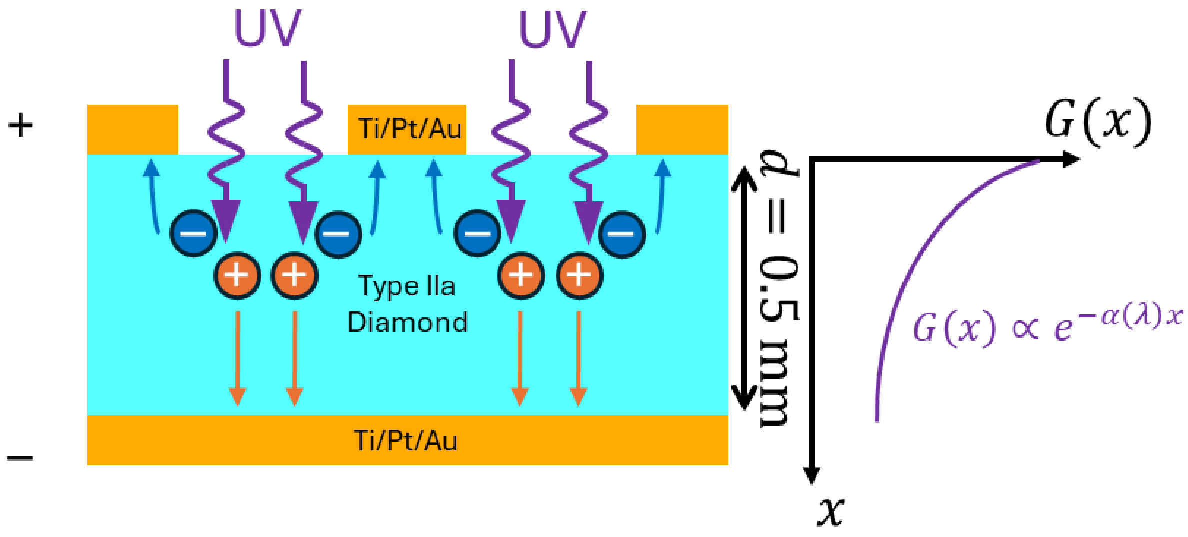
Alternative device architecture needed!

Vertical PCSS

- ✓ Higher carrier mobility due to bulk conduction
- ✓ Superior voltage handling due to reduced surface effects

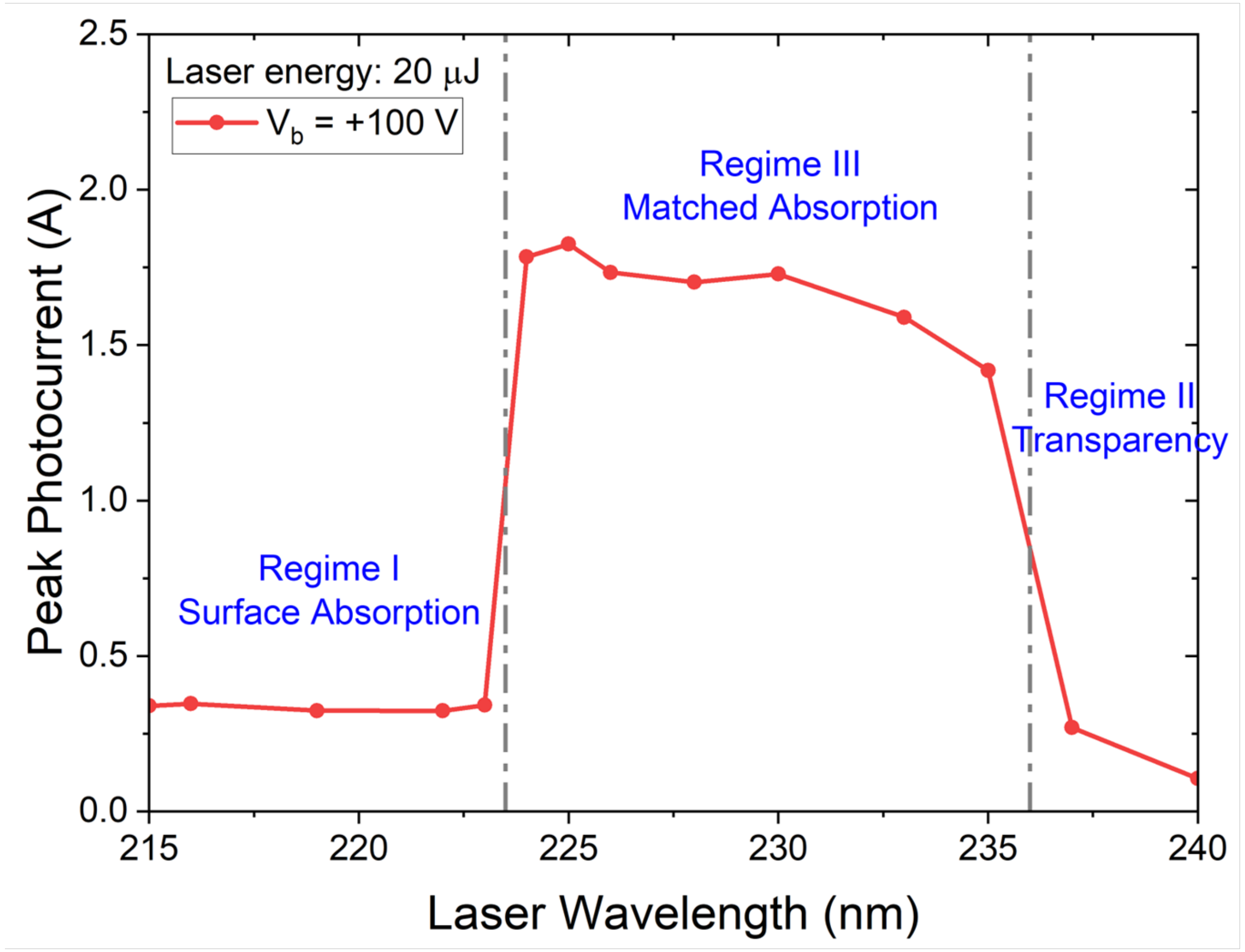
Vertical Diamond PCSS: Design and Operation

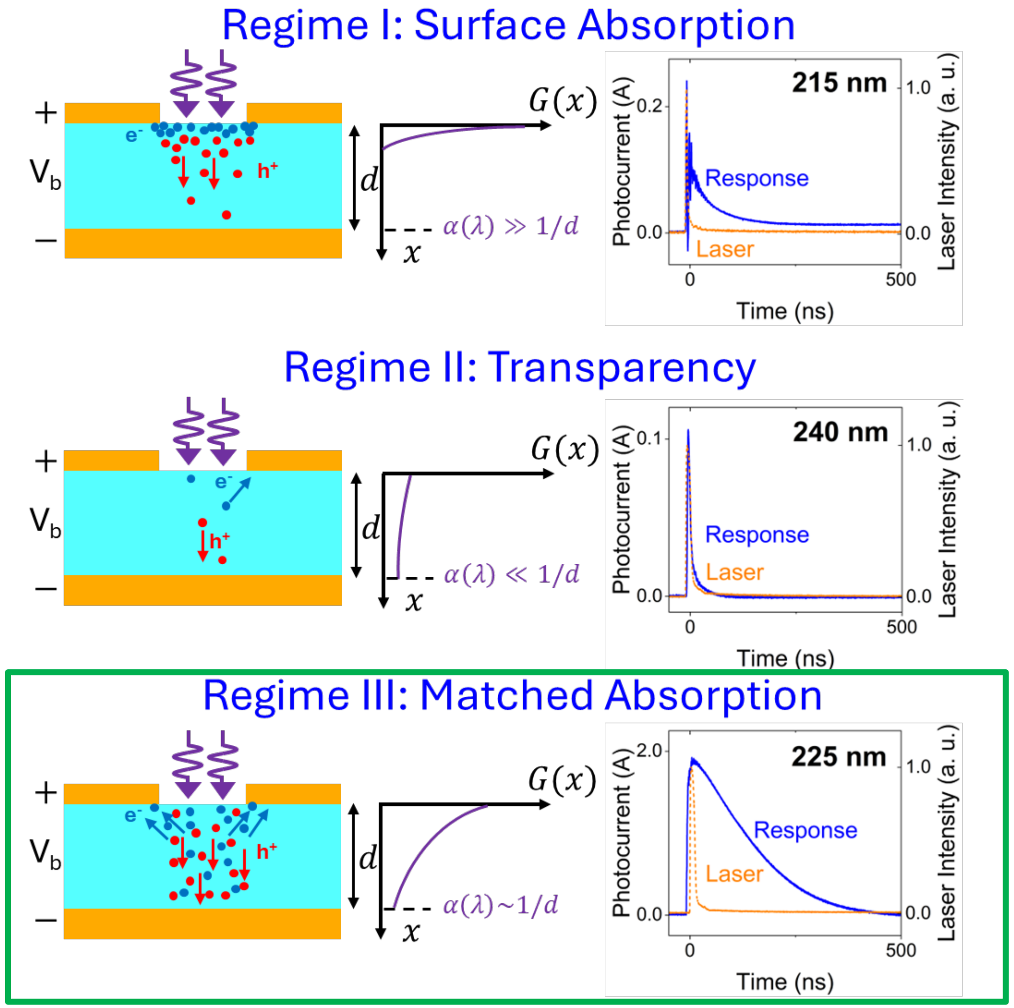




Hubert Elly, Eric Cheng, Anik Mazumder, Zhuoran Han, Jaekwon Lee, Andrey Mironov, Can Bayram; Ultrafast vertical photoconductive intrinsic diamond switch with high current (17.1 A at 1 kV). *Appl. Phys. Lett.* 23 March 2026; 128 (12): 123301.

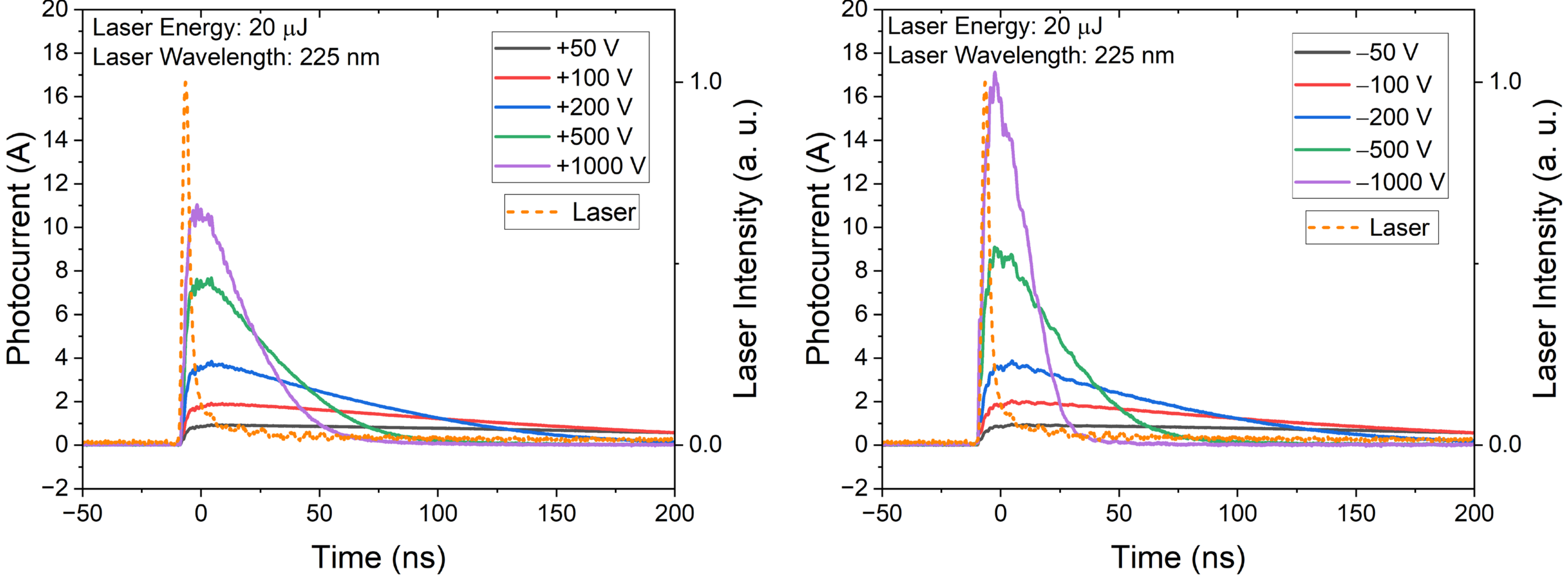
Vertical Diamond PCSS: Photocurrent Spectral Response





Vertical Diamond PCSS: Matched Absorption

Transient Response at Matched Absorption

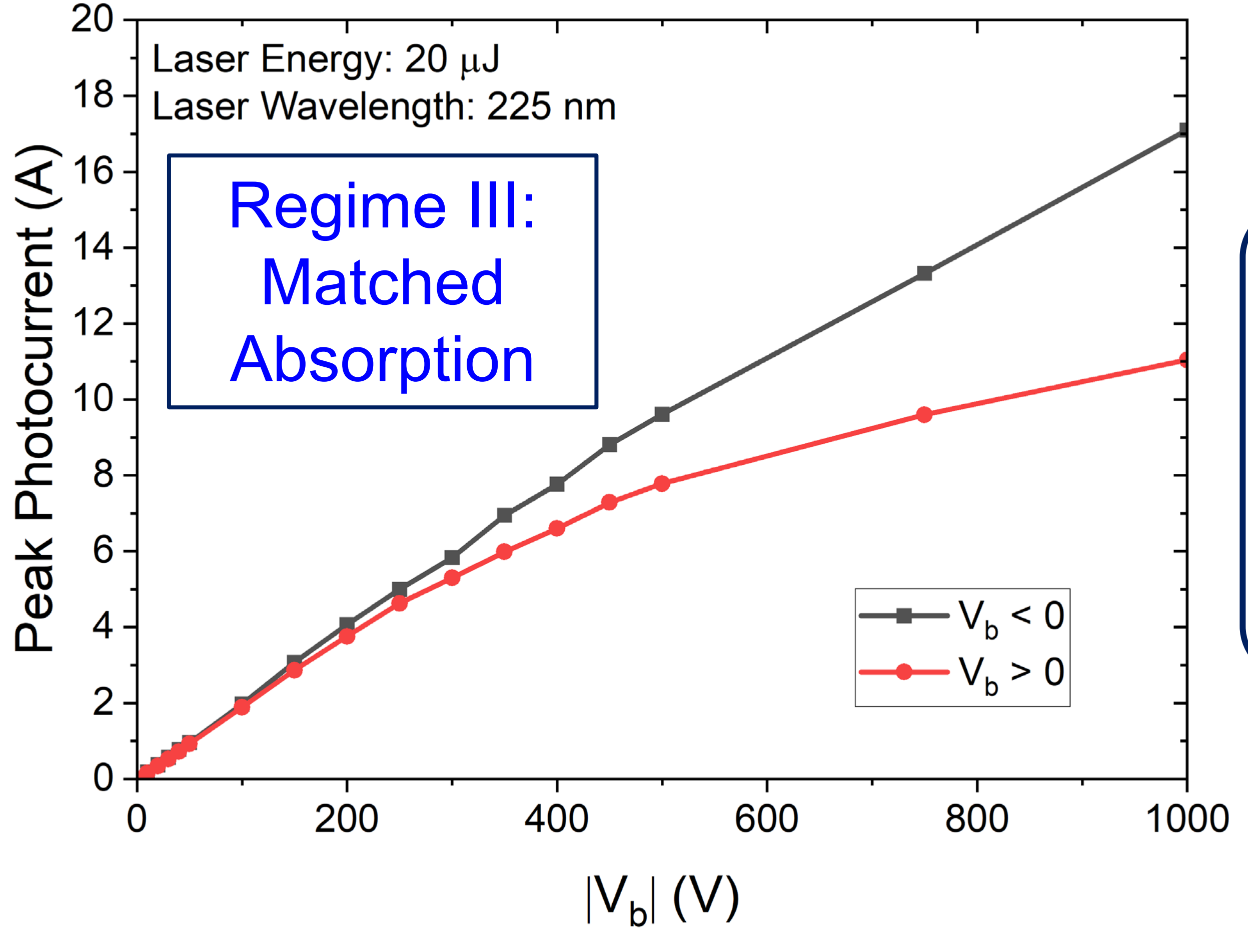


Observations

1. Peak photocurrent magnitude higher when voltage bias is negative
2. Fall time reduces with increasing voltage bias

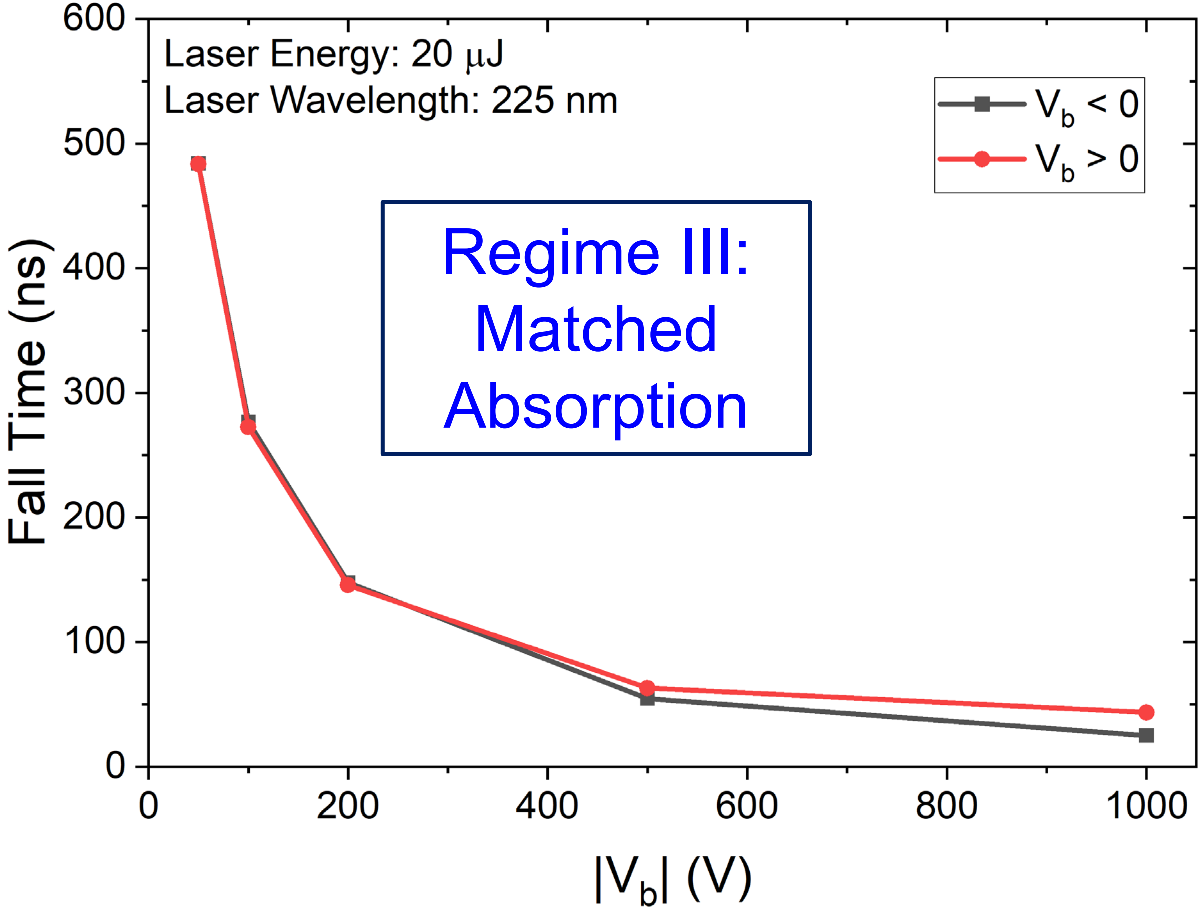
Hubert Elly, Eric Cheng, Anik Mazumder, Zhuoran Han, Jaekwon Lee, Andrey Mironov, Can Bayram; Ultrafast vertical photoconductive intrinsic diamond switch with high current (17.1 A at 1 kV). *Appl. Phys. Lett.* 23 March 2026; 128 (12): 123301.

Vertical Diamond PCSS: Photocurrent-Voltage Relationship



- Higher peak photocurrent for negative bias voltage which facilitates **electron dominated conduction cm²/V-s**
  - $\mu_e \approx 4{,}300$ cm²/V−s $\gg \mu_h \approx 2000$ cm²/V−s
- **Laser condition:** 225 nm with 20 μJ, 4 ns pulse width, and 10 Hz repetition rate
- **17.1 A achieved at -1 kV bias**

Vertical Diamond PCSS: Pulse Compression



- ❖ Photocarrier dynamics in PCSS:

$$\frac{1}{\tau_f} = \frac{1}{\tau_r} + \frac{1}{\tau_{transit}}$$

  - τ_f: carrier lifetime in diamond (fall time)
  - $\tau_{transit} = \frac{d^2}{\mu V_b}$
  - τ_r: recombination lifetime (>1 μs ≫ $\tau_{transit}$)
- ❖ **25 ns fall time at 1 kV bias**

Vertical Diamond PCSS: Benchmarking

TABLE I

PERFORMANCE COMPARISON OF HIGH VOLTAGE DIAMOND PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHES

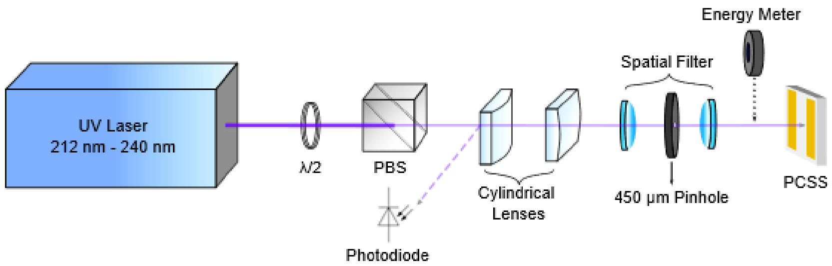
Device Structure	Trigger Mode	Laser Parameters (Wavelength, Pulse Width, Energy per Pulse)	Peak Photocurrent (A)	R_{PCSS} (Ω)	Reference
Vertical, side-illuminated	Intrinsic	222 nm, 7 ns, 400 µJ	1.0	233	Appl. Phys. Lett. **43**(2), 207–209 (1983)
Vertical, side-illuminated	Extrinsic	248 nm, 10-15 ns, 2 mJ	4.4	177.3	IEEE TED **37**(12), 2511–2516 (1990)
Vertical, front-illuminated	Extrinsic	355 nm, 17 ps, 4 mJ	14.5	18.9	ACS Photonics 11(10), 4177–4183 (2024)
Lateral, front-illuminated	Intrinsic	218 nm, 4 ns, 65 µJ	6.5	103.8	Appl. Phys. Lett. 126(15), 152105 (2025)
Vertical, front-illuminated	Intrinsic	225 nm, 4 ns, 20 µJ	17.1	8.5	This work

Note: All devices are measured at a bias voltage magnitude of 1 kV

Future work: Towards a Lamp Triggered PCSS

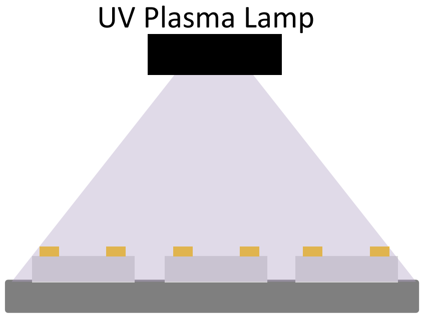
Laser-trigged PCSS

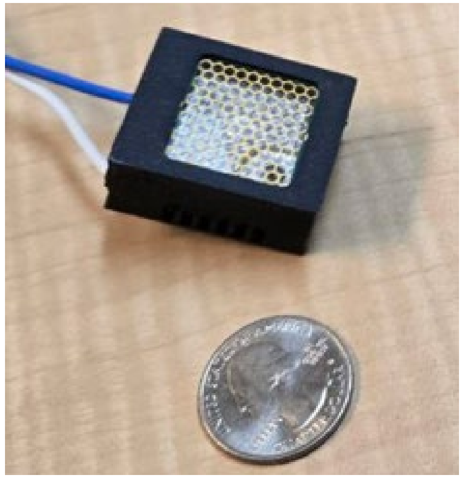
- High power consumption
- Complex, costly, and bulky optical system
- Optical alignment and uniformity across large aperture difficult to achieve



Lamp-triggered PCSS

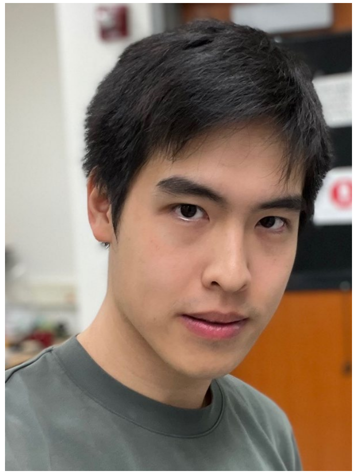
- ✓ Improved energy efficiency
- ✓ Reduced complexity and smaller footprint
- ✓ Inherently uniform over large aperture and precise optical alignment unnecessary
- ✓ Accommodates multi-die integration





*Courtesy of Professor J. Gary Eden and the Laboratory for Optical Physics and Engineering (University of Illinois)

Student Biography, Hubert Elly



Education

- 2024 – 2027 (exp.) Ph.D. Candidate in Electrical Engineering, 4.00 / 4.00
  University of Illinois Urbana-Champaign, Urbana, IL
- 2022 – 2024 MS in Electrical Engineering,
  Georgia Institute of Technology, Atlanta, GA
- 2018 – 2022 B.S. in Electrical Engineering and Physics,
  Georgia Institute of Technology, Atlanta, GA

Awards

- 2026 Nick and Katherine Holonyak, Jr. Graduate Student Award
- 2025 Promise of Excellence Fellowship

Coherent / II-VI Foundation supported journal publications

1. **H. Elly**, E. Cheng, A. Mazumder, Z. Han, J. Lee, A. Mironov, and C. Bayram, "Ultrafast Vertical Photoconductive Intrinsic Diamond Switch with High Current (17.1 A at 1 kV)," Appl. Phys. Lett. 128 (12), 123301 (2026).
2. Z. Han, J. Lee, A. Mazumder, **H. Elly**, S. Messing, A. Mironov, and C. Bayram, "Record performance in intrinsic, impurity-free lateral diamond photoconductive semiconductor switches," Appl. Phys. Lett. 126 (15), 152105 (2025).

Student Biography, Keith Chang

Education

- 2024 – 2027 (exp.) Ph.D. Candidate in Electrical and Computer Engineering, 4.00 / 4.00
  University of Illinois Urbana-Champaign, Urbana, IL
- 2019 – 2023 B.S. in Electrical Engineering,
  National Yang Ming Chiao Tung University, Hsinchu, Taiwan

Awards

- 2026 National Defense Science and Engineering Graduate (NDSEG) Fellowship (Award rate of < 7%)

Student Biography, Berre Vize

Education

- 2025 – 2028 (exp.) Ph.D. Student in Electrical and Computer Engineering, 3.66 / 4.00
  University of Illinois Urbana-Champaign, Urbana, IL
- 2022 – 2025 M.S. in Electrical and Electronics Engineering,
  Middle East Technical University, Ankara, Turkey
- 2017 – 2022 B.S. in Electrical and Electronics Engineering,
  Middle East Technical University, Ankara, Turkey

Awards

- 2025 Promise of Excellence Fellowship