U.S. Department of Energy
Advanced Research Projects Agency – Energy

Request for Information (RFI)
DE-FOA-0002835
on
Ultra-Fast-Triggered Semiconductor Devices for Enhanced System Resiliency

Objective:

The purpose of this RFI is to solicit input for a potential future ARPA-E research and development program focused on development of materials and device technologies to support advances in grid resiliency and reliability. ARPA-E seeks input from power electronics, optoelectronics, photonics, and other related communities regarding the development and demonstration of next-generation ultra-fast semiconductor devices (potentially light controlled/triggered) for enhanced resiliency and reliability of power electronics systems ranging from kilowatts to gigawatts of power. Consistent with the agency's mission, ARPA-E is seeking clearly disruptive, novel technologies, early in the R&D cycle, and not integration strategies for existing technologies.

ARPA-E desires input from a broad range of disciplines and fields, including, but not limited to power electronics, photonics, optoelectronics, optical science and microsystems, electrical engineering, circuit design, wide-bandgap and ultra-wide-bandgap materials, semiconductor devices, packaging, module, gate drive design, and others. This includes input from the developers and end-users of such technologies, such as automotive, data centers, solar and wind-interface converter systems, electric motor-driven systems, high/medium voltage transmission/distribution, rail/ship propulsion, HVDC/FACTS, and many others. ARPA-E is particularly interested in how light-triggered, ultra-wide bandgap semiconductors can help U.S. to realize more reliable, resilient, and efficient systems.

This RFI is focused on potential solutions at material/device/module level rather than circuit or system topology development and integration, although system context is desirable.

Please carefully review the REQUEST FOR INFORMATION GUIDELINES below and note in particular: the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME. Respondents shall not include any information in their response to this RFI that might be considered proprietary or confidential.**

Background:

Power electronic conversion systems are capable of decoupling dynamics between system sources, distribution, and loads, while improving system controllability, reliability, resilience, and efficiency. These benefits are already being realized in a variety of applications, such as electric cars, ships, and airplanes, where power electronics replace traditional thermal, mechanical, hydraulic, and pneumatic systems. To realize these benefits in grid applications and to enable widespread integration while maintaining and improving grid resiliency and reliability, new approaches are needed to overcome several technical challenges, including:

- Device operation at voltages and currents more compatible with H/MV grid requirements (15 kV-110kV+)
- Electromagnetic Interference issues and losses being driven by increased switching speed
- Ultra-fast switching required to protect against faults and power surges (avoiding thermal overload)

Despite great strides made, today's semiconductor power electronics suffer from performance limitations.

They still cannot reach current and voltage levels required by high and medium voltage (H/MV) grid applications, requiring series and/or parallel stacking of multiple devices in multi-level modules to meet current and voltages requirements. This poses challenges to reliability and introduces additional complexity and cost due to increased part count.[1] Theoretical limitations of performance of a single device are related to fundamental material properties, such as critical field. While wide band gap (WBG) materials are pushing device performance to higher voltage and current levels, relative to Si, ultra-wide band gap (UWBG) materials are even more attractive with their superior properties. However, they suffer from significant challenges, for example difficulty with doping and material quality. [2] Optically stimulated ionization of deep dopants may offer a solution to this problem, along with other novel options.[3]

The trend of increased switching speed of power electronic conversion, driven by reduction of size, weight and power (SWaP) and switching losses, is driving the electromagnetic interference (EMI) issues, which must be managed at an increased system complexity and cost.[4] Elimination of electrical connections to the gate, such as that offered by optical interconnects, offers a potential solution to mitigating this problem. A related benefit may include advances in device/module stacking and control.

Although power electronics are more capable than traditional solutions, they do need to be protected at lower power levels because they are smaller and cannot handle the thermal loads. Thus they may need to be switched off faster to be protected against faults. Additionally, some grid threats (typically associated with space weather or certain categories of man-made threats) are expected to create fault conditions at much faster speeds than current protection systems can address. Improving the temporal response of grid protection devices is needed.

The growing penetration of power electronics as grid interfaces will also require the development of new control architectures, algorithms, and systems, capable of regulating power electronic interfaces on a sub-microsecond scale, rather than current high inertia, slow mechanical interfaces. Consequently, small perturbances can cause instabilities in frequency and line voltage, which can lead to further outages. To address this problem, the development of power electronic devices with improved performance (i.e., operation at voltages and currents more compatible with H/MV grid requirements) and faster operation (to enable more sophisticated grid control methods) is needed.

ARPA-E seeks solutions to development of power electronics capable of overcoming these challenges through a variety of approaches, such as (but not limited to) development and demonstration of devices based on UWBG materials, utilization of optical stimuli to modulate conductivity, application of optical

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[1] O. Alavi et al., "A Comparative Reliability Study of Three Fundamental Multilevel Inverters Using Two Different Approaches," Electronics, 2016; Available Online: https://www.mdpi.com/2079-9292/5/2/18

[2] J. Y. Tsao et al., "Ultrawide-Bandgap Semiconductors: Research Opportunities and Challenges," Wiley Online Library, 2017; Available Online: https://doi.org/10.1002/aelm.201600501

[3] S. K. Mazumder, "An Overview of Photonic Power Electronic Devices," *IEEE Transactions on Power Electronics*, 2016

[4] F. Zare, "EMI Issues in modern power electronics systems," QUT, 2009; Available Online: https://eprints.qut.edu.au/31175/2/31175.pdf

gate control to improve switching performance, EMI immunity, efficiency, and reliability. ARPA-E is most interested in learning about potential solutions at material/device/module level rather than circuit or system topology development and integration, although would want to understand how demonstration of specific device performance will impact and/or enable potential future control approaches.

Purpose and Need for Information:

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future programs intended to help create transformative device technologies that will eventually enable innovative control systems for improved grid resiliency and reliability. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI on a non-attribution basis. This RFI provides the broad research community with an opportunity to contribute views and opinions regarding the advanced circuit topologies development path, energy use and adoption consideration in relevant end-use applications. Based on the input provided in response to this RFI and other considerations, ARPA-E may decide to issue a FOA. If a FOA is published, it will be issued under a new FOA number. No FOA exists at this time. ARPA-E reserves the right to not issue a FOA in this area.

REQUEST FOR INFORMATION GUIDELINES:

ARPA-E is not accepting applications for financial assistance or financial incentives under this RFI. Responses to this RFI will not be viewed as any commitment by the respondent to develop or pursue the project or ideas discussed. ARPA-E may decide at a later date to issue a FOA based on consideration of the input received from this RFI. No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E reserves the right to contact a respondent to request clarification or other information relevant to this RFI. All responses provided will be taken into consideration, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that might be considered proprietary or confidential.**

Responses to this RFI should be submitted in PDF or Word format to the email address ARPA-E-RFI@hq.doe.gov by **5:00 PM Eastern Time on September 9, 2022**. ARPA-E will not review or consider comments submitted by other means. Emails should conform to the following guidelines:

- Please insert "Responses for RFI for FOA DE-FOA-0002835" in the subject line of your email, and include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research, and development center (FFRDC), government-owned/government-operated (GOGO), etc.), email address, telephone number, and area of expertise in the body of your email.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential methodologies.

QUESTIONS:

ARPA-E encourages responses that address any subset of the following questions of relevance to the respondent and encourages the inclusion of references to important supplementary information.

1. **Materials/devices for improved high speed, high voltage, high current device performance:**
   a) What strategies could be employed to overcome the issue of poor room temperature ionization of dopants in UWBG materials (due to donor levels deep in the bandgap), for example optical excitation of carriers to induced conductivity to facilitate high electron and hole mobility?
   b) How can issues of thermal conductivity and electron and hole mobility discrepancies in UWBG materials be addressed?
   c) What are other obstacles preventing UWBG materials from more widespread utilization in grid and other power electronic applications (cost, reliability, material quality, packaging, ohmic contacts). Where possible, please quantify the gap between what is required vs state of the art.
   d) What else (besides UWBG materials) should be pursued to improve voltage/current and switching performance (switching frequency, slew rates, etc.) on a single device basis? What barriers exists to demonstrating these device concepts and how can they be overcome?
   e) How can we improve insulating dielectric materials (in terms of their voltage handling capabilities, reliability and/or lifetime, thermal, or any other relevant parameters) or other non-conductive components for reliable, fast, high voltage devices?
   f) Photoconductive semiconductor switches (PCSS) with both linear and high-gain regimes are potentially promising for high speed, high voltage/current performance - what materials are best suited for this application and why? What device types and potential new device topologies could take advantage of non-linear and linear PCSS phenomena and how could they add value for future power electronic circuitry for conversion, regulation and protection of electrical loads, generation, and distribution/transmission systems? What are obstacles to implementation and how could they be overcome?
   g) What are opportunities for improvements of other state-of-the-art power electronic devices employing optical triggering, such as light-triggered GTOs, IGCTs, and ETOs. How could they be improved and what stands in the way?
   h) What would be appropriate metrics and corresponding transformative performance targets to evaluate improvements in UWBG or other devices – current, voltage or power metric, temporal performance such as switching time or frequency?
   i) Should ARPA-E target an integrated microsystem performance – i.e., UWBG device, optical control device and its drive electronics, thermal management in a package? Is there an advantage in monolithic integration of optical and power electronic functionality or is a solution integrated at a chip or board level acceptable? What performance metric could capture the tradeoffs involved in this decision?
   j) What are the options to minimize light source energy used for triggering? What metrics would best capture the goal of minimizing light source energy?

2. **EMI mitigation:**
   a) How, and by how much, can optical gate control improve EMI immunity in power electronic modules? What are appropriate metrics for devices/modules utilizing optical gate control that capture the value proposition of optical gate control?
   b) What stands in the way of optical gate control implementation and what are possible mitigation approaches? What trade-offs would such an implementation require?
   c) What novel control schemes/systems could be enabled by optical gating in multi-level converters or other module types and how could they benefit performance in a variety of applications ranging from grid control and protection, power conversion for applications such

as EVs, aviation, industry electrification, consumer goods and so on? What are obstacles to implementation and how could they be overcome?

d) How could optical gate control contribute to further reduction of switching losses, reliability improvements and other improvements? What are the barriers and how could be overcome?
e) What other benefits could be realized by utilization of optics and photonics or other novel approaches in power electronic applications ranging from grid control, power conversion for applications such as EVs, aviation, industry electrification, consumer goods and so on?
f) Are there other distinct benefits in galvanic isolation? What are they and how can they be quantified? In what applications is this particularly important and why?
g) What are other approaches to mitigating EMI and allowing for galvanic isolation? What are challenges in their realization and proposed mitigations?
h) How could optically triggered devices enable simplified device and module stacking for higher equivalent voltage and current performance? Does optical triggering create opportunities for novel control schemes? If so, what are they, what are obstacles to their implementation and potential mitigation methods?

3. **Other devices for Power Electronic systems resiliency/protection:**
   a) What other devices/components required to improve grid resilience need improvement and in what way (MOVs, bi-directional switches other surge protection schemes and devices)?
   b) Are existing sensing capabilities sufficient and if not, what is needed (types of sensors, performance, cost, reliability metrics)? What advances are needed to make these new sensor capabilities viable (technically and economically)?
   c) What novel devices could be realized for grid protection, how would they fit into or improve grid control schemes/systems? How are they better than what is currently available? What are obstacles to implementation and how can they be overcome?
   d) How could power electronic devices with sub-microsecond reaction times impact grid system resiliency, reliability, and protection? How could they impact other, related areas such as EVs, aviation, industry electrification, consumer goods and so on?

4. **System impact:**
   a) What specific control schemes/approaches could be enabled by innovations proposed in this RFI? What other device/module level innovations are needed to advance our capability to control and regulate the current and future grid? Are there other applications that could benefit (EVs, electric aviation, microgrids, wireless power transfer)?
   b) What are performance limitations of current devices utilized in grid protection and control, what system level impacts could be realized if device performance was improved? What stands in the way of those improvements?
   c) Which part(s) of the grid is/are most vulnerable to disruption/failure and why? How is it currently protected, to what levels, and are those appropriate? What improvements could/should be implemented (potentially utilizing device/module advances posed in this RFI, but also other ideas) in order to mitigate those vulnerabilities? What is necessary to make that happen?
   d) What benefits and tradeoffs are associated with the integration and type of optical power device control? For example: direct optical modulation of power device conductivity vs. optical modulation of conductivity of auxiliary, intermediate low power device that controls

the primary power device vs. optical ON/OFF control of primary power device (such as traditional optical fiber coupled gate control).

5. Metrics:
    a) Would a separate set of metrics for modules vs. devices be appropriate?
    b) Which metrics would you trade against each other?
    c) What would be appropriate metrics for reliability, lifetime, number of switching operations?
    d) While we envision room temperature operation, what are specific application-relevant thermal considerations?

Please provide feedback on the proposed performance targets and provide alternative proposed targets and comments in the "Proposed Target" column. If there are additional metrics that are missing, please add rows and values to represent them:

Table 1: Performance Metrics

Category	Target	Proposed Target
Rated Device Voltage	≥ 10 kV	
Device Current	≥ 100A	
Switching frequency	≥ 200 kHz	
Switching loss reduction	30% of SOTA	
Turn-On/Off time	< 0.1 µs	
Turn-On delay	< 3 ns	