SiC BiCMOS Platform Development - SIC

Problem Statement

OBJECTIVE: To develop a BiCMOS platform utilizing SiC wafer to achieve high temperature operation and high voltage/power integration.

DESCRIPTION: As a result of almost four decades long investment on SiC technology by DoD and technical breakthroughs achieved by private sectors, affordable high-voltage SiC MOSFETs debut in the market recently [1][2]. The 650+V SiC MOSFETs become popular switching devices in data center, renewable energy, and even electric vehicle applications thanks to excellent energy efficiency and reduction in the power conversion system size and weight.

While discrete SiC power devices are successfully commercialized, separate efforts to develop SiC integrated circuits (ICs), that can be used in high temperature and high radiation environments, have continued for a decade. Those ICs were mostly based on non-CMOS, (i.e. bipolar transistor [3], MESFET [4] and JFET [5][6]) due to many technical barriers in SiC CMOS technology such as low channel mobility, uneven performance of NMOS vs. PMOS, forming resistive ohmic contacts, and gate oxide reliability.

More recently, advantages such as convenient digital circuit design using standard libraries and low power consumption of CMOS configuration drive big corporations [7][8] and small businesses [9][10] to jump into the SiC CMOS IC development competition. Despite these aspirations and effort, decent SiC CMOS technology development will not be easy to overcome the fundamental material properties of SiC including high gate oxide/SiC interface states.

The goal of this solicitation is to develop and demonstrate a SiC BiCMOS platform that can be applied up to 300°C ambient temperature. Base materials for this solicitation include, but are not limited to bulk or epitaxial SiC wafer, Si/SiC direct bonding (Si/SiC DB) wafer, or Si-epitaxial grown on SiC substrate (Si-epi/SiC) wafer.

For this exam, focus on the following…
Per the instructions below and the additional guidance provided during your Candidacy Exam training sessions, prepare a research and development proposal, that if funded will allow you to ***conduct a Feasibility Study that addresses the gate oxide related parameters such as channel mobility, gate tunneling current, time-dependent dielectric breakdown (TDDB), bias temperature instability (BTI), and yield (extrinsic failure rate). Key parameters related to the gate oxide should meet requirements as below.***

- NMOSFET channel mobility > 50 cm2/Vs
- PMOSFET channel mobility > 10 cm2/Vs
- Threshold voltage shift (for NMOSFET and PMOSFET) < ±500 mV at bias-temperature stress during mean time to failure
- When Si/SiC DB or Si-epi/SiC wafers are used, Si/SiC interface and across-wafer uniformity should be characterized by various imaging tools and spectroscopy. All junction combinations between (n and p-type) Si and (n and p-type) SiC have to be characterized electrically to monitor the ohmic and p-n junction behavior. Key parameters related to SiC/Si interface should meet requirements as below.
- Void free and continuous SiC/Si interface throughout entire wafer
- Bonding interface thickness (thickness of SiO2, amorphous Si or carbon rich region) < 10 nm
- Bonding interface state density < 1x1012 eV-1cm-2

REFERENCES:
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[7] N. Ericson , 'A 4H Silicon Carbide Gate Buffer for Integrated Power Systems,' IEEE Transactions on Power Electronics, 2014;
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KEYWORDS: SiC, BiCMOS, Si/SiC heterojunction, integrated circuit, high-temperature, high-voltage

You are the Chief Technology Officer of a company that has specialized in creating low volume customized high reliability SiC power electronics systems for specific applications in demanding environments. Your CEO believes that the company's expertise in micro to nanoscale SiC based materials, processing, and devices could provide a research and development path to meet DOD objectives in their solicitation. Your job is to define the research and development needed for new base technologies that would provide the platform for many future SiC BiCMOS technologies, and perhaps even expansion into other harsh environment markets (aircraft, spacecraft, etc.).

While meeting the DOD performance requirements are your priority, the cost of customized systems for SiC BiCMOS improvements could be high, initially, as compared to off the shelf commercial systems. In order to have potential to be competitive in other market applications which value compact, high-performance, it is desirable if your approach can be easily modified or adapted for lower price-point markets.

Your job as CTO is to deliver a complete proposal with your plan for the company to compete in this area to your CEO by your deadline.

YOUR DELIVERABLE

Your task is to write an internal proposal for your corporate officers describing your idea for research and development. The proposal should include all components, sections, etc. per your Candidacy Exam Template and SOP/Guidance documents.

Most Importantly – The fundamental rationality and reasonableness of your proposed solution is of critical importance. The significance and novelty of your creative solution, one that moves the boundaries of knowledge outward, is also of critical importance.

The list below is just a minimum list of issues you might consider and provides additional guidance regarding what you should address in the relevant sections of your proposal (written exam). There may be many more. The point is that your proposal ***should contain the evidence*** needed to make an effective and compelling case to your CEO in order to ensure that they make the right decision.

The guidance below can be used to help you with the preparation of some of the more unfamiliar content required per the Template document. At a minimum, and within the guidelines provided by the SOP and Template documents, be sure you address all of the following additional items where relevant in your written exam response.

Current Science and Technologies – What is already being done in this area by other researchers, companies and governmental institutions? Describe the current state-of-the-art for both the science and the implementation. Use diverse resources such as science literature, journals, conference proceedings, the internet, patents and other sources of existing public knowledge. ***Cite all references you use and use quotes for any word-for-word transfer to your report.***

Your Design Approach – What is the basis for your design approach to the problem? Why is your technology better than existing technologies? What technology attribute(s) make it likely to be selected by DOD? Address scientific *and* engineering aspects of these questions. Where relevant, consider: device size, weight and power (SWAP) requirements; materials of construction; critical components and considerations that comprise the complete device-level or subsystem-level solution; and what are the required prototyping and/or production methods, tools and costs? ***Even if you are not an expert in all of the technological areas required to bring the end-product to fruition, you should at least be able to intelligently discuss the other critical components, considerations and R&D requirements.***

Research & Development Plan – Describe a set of tasks and/or tests you will complete to demonstrate that your approach is effective and that your implementation of the solution is meritorious of further R&D. ***This is essentially your design of experiments. What are your objectives? What are the tasks required to achieve those objectives?*** Where applicable answer the following:

i) What are the key product specifications that you are targeting and how do they compare to the specifications of the existing solution(s) if any exist?
ii) What mathematical models and/or simulation constructs will you use to validate your approach, especially if prototyping and test trials are costly?
iii) What are the key dependent and independent variables that you must utilize and evaluate to confirm the proposed solution works?

Above all, be specific and detailed about the key tasks to confirm feasibility and validity of what you are proposing.

Cost Analysis – Identify cost and market issues that will impact the pricing strategy of the solution you have proposed. Identify Strengths, Weaknesses, Opportunities and Threats (SWOT) in the market place. If you are unfamiliar with the typical SWOT marketing analysis, I encourage you to 'google it'. Consider such things as: the major cost items that would impact the implementation; which elements of your implementation solution would be handled in-house versus externally-sourced; major risk elements that could drive up costs if the primary path item fails; costs of IP licensing needed, etc. Provide justification and/or reasoning behind your decisions. Avoid subcontracting design, manufacture or assembly of any *proprietary* component outside the company, because the CEO is concerned with potential IP leakage. Utilizing suppliers of common materials or devices is acceptable.

Hint – Clearly state your hypothesized solution. Identify its innovation(s) and advantages relative to state of the art. Describe both existing data, and work needed to support each aspect of the hypothetical solution. Consider theoretical, fabrication, and characterization aspects: for each, identify software/equipment and methods to use, parameters to vary, anticipated outcomes, and possible alternatives in the event of unsatisfactory results. Discuss material, process, device, and systems aspects of your solution. *Refine* your hypothesized solution as you accumulate information

and prepare the manuscript. **Remember**: clearly distinguish what is known from what is hypothesized or not known. What is needed to distinguish the important things to know?

Refer to the 2021 MSEN PhD Candidacy Exam SOP and Guidelines and the MSEN PhD Candidacy Exam Template documents for all additional instructions.