ACCELERATING THE R&D OF MEASUREMENT, ABATEMENT, AND ALTERNATIVES

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SEMICONDUCTOR RESEARCH CORPORATION (SRC)
TODD.YOUNKIN@SRC.ORG
OUTLINE

• BOTTOM LINE UP FRONT (BLUF)

• WHO AM I AND WHO IS SRC?

• WHAT HAS SRC HISTORICALLY DONE IN ESH?

• WHAT IS SRC CURRENTLY DOING IN ESH (AND PFAS)?

• WHAT COULD SRC DO IN ESH OR “SSM” THRU REGIONAL R&D LIKE THROUGH NSTC?

• CALL TO ACTION

**ESH** = Environment, Safety, and Health

**SSM** = Sustainable Semiconductor Manufacturing
• SRC WORKS AT THE 5-15 YR. TIME HORIZON, ACCELERATING LEARNINGS AND SOLUTIONS INTO INDUSTRY
• SRC HAS A 29-YR. COMMITMENT TO ESH* R&D AND WFD FOR SEMI

• PFAS** IS A CLASS OF THOUSANDS OF CHEMICALS WITH A COMPLICATED CHEMICAL AND POLICY LANDSCAPE
• THIS CLASS OF MATERIALS IS OF GROWING PUBLIC CONCERN AND REGULATORY AGENCIES ARE RESPONDING
• PFAS ARE CRITICALLY IMPORTANT TO SEMICONDUCTOR MANUFACTURING
• CURRENTLY NO KNOWN SUBSTITUTES FOR MOST, POSSIBLY ALL, OF THE APPLICATIONS THAT USE PFAS

• SRC APPLAUDS THE EFFORTS OF SIA’S PFAS CONSORTIUM AND SEMI’S CLIMATE CONSORTIUM
• REGIONAL GOV’TS NEEDED TO HELP INDUSTRY MAKE A COLLECTIVE COMMITMENT TO THE R&D OF SOLUTIONS

• WE MUST PROVIDE SUFFICIENT TIME TO IDENTIFY AND QUALIFY SUITABLE REPLACEMENTS
• THIS REQUIRES SIZEABLE INVESTMENTS, GOAL CLARITY, AND A SENSE OF SHARED URGENCY

BUILDING A PATH FORWARD
WHO AM I?

Ph.D. Organometallic & Polymer Chemist


2.5 yrs. as President & CEO of SRC (2020-Today)

I AM an ESH + SSM Champion

I AM NOT an ESH + SSM Expert in the Policy or Fab Trenches
"We need to channel more funds to research and add to the supply and quality of degreed professional people."

-Robert Noyce

41 Years
Neutral, Trusted, Science-Driven
>$2.5B in R&D Investments
>16,000 SRC Scholar Alumni
Drive & adapt to industry needs
COLLABORATIVE R&D CREATES TECH TRANSFER AND HIRES!

In 2022, SRC exceeded its Technology Transfer and Scholar Hiring goals. With support, SRC can scale up to 5x↑ annually to improve its reach and speed.
CHIPS ACT HAS SPURRED $214B IN PRIVATE SEMI ANNOUNCEMENTS

U.S. Chips & Science Act
August 9, 2022
$39B for Manufacturing; $11B for R&D

https://www.whitehouse.gov/invest/

SRC Member Companies
Analog Devices (OR)
EMD Electronics (PA)
GF (NY)
IBM (NY)
Intel (AZ, OH, NM)
Micron (ID, NY)
NXP (TX)
Samsung (TX)
SK Group (GA, MI)
Texas Instruments (TX, UT)
TSMC (AZ)

11 SRC Member Companies have announced $190B (89%) in new U.S. semiconductor investments with ~35k direct jobs (~200k jobs estimated)
**SRC’S THREE PILLARS FOR SEMI’S “ROARING 20S”**

**Prosperity**
- **Nov 2020**
  - 2030 Decadal Plan for Semiconductors
    - **3x↑ in Annual Funding**
  - NIST Roadmap for Microelectronics and Advanced Packaging (MAPT)

**The People**
- **Apr 2021**
  - Broadening Participation Pledge
    - **3x↑ Scholar Pipeline** (AA-PostDoc)
  - Greater Diversity, Equity, & Inclusion
  - Ignite passion for Semi in US Workforce Advisory Board (WAB)

**The Planet**
- **Oct 2021**
  - Commitment to Sustainability
  - Green Materials & Processes
  - Energy Efficient ICT Systems
  - Win Hearts & Minds of Next Gen Innovators

Since Spring ’22, SRC has used these 3 criteria to direct $350M+ in R&D & WFD investments

BUILDING A PATH FORWARD

#SEMICONWest
OUR COMMITMENT TO SUSTAINABILITY

SRC will drive an R&D agenda that delivers **greener materials and processes** for semiconductor manufacturing, creates chips and packages with **radically improved energy efficiency**, and drives a revolution in the efficiency of future information and communication technology systems **at scale**.

READ MORE AT SRC.ORG/SUSTAINABILITY

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An Open Letter to the SRC Board Published on **Sustainability Day** (Last Wed in Oct)

BUILDING A PATH FORWARD

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SRC’S ESH* PROGRAM, HISTORICALLY AND TODAY

- **29 YRS** OF CONSECUTIVE INVESTMENT IN SUSTAINABLE SEMI MANUFACTURING (SSM)
- **>$65M** INVESTED, 1994 THRU DEC, 2027
- OUR ACTIVE ESH PROGRAM IS **$1.25M/YR.**
- **3 YR**, UNIVERSITY-LED RESEARCH PROJECTS
- **6 CORPORATE MEMBERS** LED BY INDUSTRY EXPERTS

<table>
<thead>
<tr>
<th>Advisory Board Member</th>
<th>Member Company</th>
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<tbody>
<tr>
<td>Tim Yeakley, Chair</td>
<td>Texas Instruments</td>
</tr>
<tr>
<td>David Speed, Vice Chair</td>
<td>Globalfoundries</td>
</tr>
<tr>
<td>Brooke Tvermoes</td>
<td>IBM</td>
</tr>
<tr>
<td>Bob Leet</td>
<td>Intel</td>
</tr>
<tr>
<td>Ralph Dammel</td>
<td>Merck KGaA (EMD Electronics)</td>
</tr>
<tr>
<td>Stefan Uhlenbrock</td>
<td>Micron</td>
</tr>
</tbody>
</table>

Thank You!
ESH HAS EVALUATED AND ENABLED ENVIRONMENTALLY FRIENDLY MANUFACTURING SOLUTIONS FOR WAFER FABRICATION AND PACKAGING / TESTING

RECENTLY BINNED HISTORICAL PROJECTS INTO CATEGORIES & MATERIAL CLASSES

MANY ARE INTER-RELATED, BUT “FLUORINATED COMPOUNDS” BEST MATCH THE CURRENT MINDSET ON PFAS AND FLUORINATED “FOREVER CHEMICALS”

LIKELY UNDERREPRESENTING SRC’S INVESTMENT SINCE SOME OF THE GREEN ALTERNATIVES (~32%) AND EBSM RESEARCH CENTER (~26%) OBJECTIVES ARE HARD TO BIN

ESTIMATE ~13% (~$8.5M) OF OUR ESH PORTFOLIO SINCE 1994

*PFC = PerFluorinated Compounds, PFOS = PerFluorOctane Sulfonate, PFAS = PerFluoroAlkyl Sulfonate compounds, PFAS = Per- and PolyFluoroAlkyl Substances
*EBSM = 2001 Research Center with SRC, Sematech, NSF, plus 19 Companies, Universities, and Affiliates

Building a Path Forward
A RECENT ESH SUCCESS STORY

NOVEL ELECTRICAL DISCHARGE PLASMA-BASED PROCESS FOR THE TREATMENT OF FAB WASTEWATER

Clarkson team "demonstrated viability," developing "a process that is the most effective and efficient technology for the removal of long-chain, short-chain, and even ultra short-chain PFAS from factory wastewater" thanks, in part, to SRC’s industry engagement.

Ms. Osakpolo "Faith" Isowamwen. Her advisor calls her a "brilliant, independent and hardworking individual but as a researcher who thinks and stays two steps ahead" and "is determined to pursue a career with a strong environmental focus."

The inaugural SRC award was granted at TECHCON-2022 in Austin, TX to Prof. Selma Mededovic of Clarkson University for leading this groundbreaking industry-relevant and impactful research.

Profs. Selma Mededovic and Thomas Holsen, (shown here w/ DMAX Plasma, LLC., 2019 SBIR) win a 3-year SRC sponsored research agreement to build upon the momentum of their outstanding research, to date.

BUILDING A PATH FORWARD

#SEMICONWest
Growing emphasis on understanding and removal of Per- and Polyfluoroalkyl Substances (PFAS)

Treatment and abatement technologies for effluent, emission, and waste management

Alternative chemistries that eliminate or reduce hazardous materials or pose environmental and human health risk

Improvement of processes and systems to reduce energy and material use and minimize waste generation

Reduction and return of high purity water

Real world measurement and metrology is a key element of all these objectives
PFAS-ONLY PROJECTS AND FUNDING HAVE SEEN INCREASED FOCUS

Number of Project Starts by Year

PFAS Research Funding (\$,USD) by Year

8 Projects, Total Funds ~$ 2M

Increased Focus on PFAS
SRC GETS ~3-5X MORE GOOD IDEAS THAN DOLLARS AVAILABLE

89 Round 1 Whitepapers received from 85 Principal Investigators out of 65 Universities from 3 countries

<table>
<thead>
<tr>
<th>Broad Category</th>
<th>Category</th>
<th>Number of Whitepapers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-PFAS (60)</td>
<td>Green Manufacturing - Other</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Other ESH</td>
<td>47</td>
</tr>
<tr>
<td>PFAS (29)</td>
<td>Analytical - PFAS</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Green Manufacturing - PFAS</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Toxicity - F Chem</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Toxicity - PFAS</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Treatment - PFAS</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>89</td>
</tr>
</tbody>
</table>

Total requested funding = $10.5M/yr. or $31.5M

Only 6% of ideas received ($630k/yr.) will be funded for Jan 1, 2024 start

Our Technical Advisory Boards (TABs) have consistently stated that SRC could award and direct ~3-5x more proposals without any loss of merit

BUILDING A PATH FORWARD
The WHAT

January 2021
2030 Decadal Plan for Semiconductors

181 participants
81 organizations

The HOW

March 2023
NIST Microelectronics & Advanced Packaging Technologies (MAPT) Roadmap - Interim

279 participants
109 organizations

Includes ESH or SSM
"One of the greatest challenges facing the semiconductor industry today is the use of PFAS, a chemical class representing thousands of different compounds that are used pervasively throughout multiple industries including the semiconductor industry..."

**Table 2. Overview of PFAS use within semiconductor manufacturing.**

<table>
<thead>
<tr>
<th>Application</th>
<th>PFAS Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photolithography: photoacids, antireflective coatings, immersion barriers, surfactants</td>
<td>Thermal stability (low and high temperatures); low volatility; chemically resistant; good compatibility with photoresist; transparent at key wavelengths; strong non-nucleophilic photoacids; inert; good solubility</td>
</tr>
<tr>
<td>Etching gases/chamber cleans: tetrafluoromethane (CF₄); hexafluorobutadiene (C₆F₆); octafluorocyclobutane (C₈F₈)</td>
<td>High selectivity, surface reaction, and etch rate. F-containing gas forms a volatile compound with Si substrate.</td>
</tr>
<tr>
<td>Advanced packaging materials: Adhesives, substrate buildup, flux</td>
<td>Chemical compatibility, required photoactive hydrophobicity/wetting control, reduces surface energies, high temperature stability, defoaming, surfactant</td>
</tr>
<tr>
<td>Wet etch chemistries</td>
<td>Nonfoaming, high selectivity for SiO₂, low particulate adhesion, excellent surface smoothness, nonreactive with other chemicals in etch formulation</td>
</tr>
<tr>
<td>Heat transfer fluids/thermal test fluids: Used to maintain process temperatures (-60°C to 80°C) in test equipment</td>
<td>Low viscosity and the low temperature dependence of viscosity, appropriate dielectric properties, wide operating temperature range, low surface tension, chemical stability</td>
</tr>
</tbody>
</table>
*SRC is also pursuing a Manufacturing USA Institute and working to support and feed other NSTC technical centers, the NAPMP, and the NIST Metrology program.

**The WHAT**
- **Decadal Plan for Semiconductors**
  - Full Report
  - January 2021
  - 2030 Decadal Plan for Semiconductors
  - 181 participants
  - 81 organizations

**The HOW**
- **MAPT**
  - Microelectronic and Advanced Packaging Technologies Roadmap – Interim Report
  - March 2023
  - NIST Microelectronics & Advanced Packaging Technologies (MAPT) Roadmap - Interim
  - 279 participants
  - 109 organizations

**SRC Implementation**
- **Kicked-off Sustainable Semiconductor Manufacturing (SSM) Initiative**
  - Jan 2023+
  - SRC Exploring Multi-Regional Partnership with SEMI for NSTC R&D

**NSTC Sustainable Semiconductor Manufacturing (SSM)**
- Includes ESH or SSM

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SUSTAINABLE SEMICONDUCTOR MANUFACTURING (SSM)

PROPOSED INITIATIVE

- Regional Gov't's provide funds to Industry & Academia to explore sustainable semi manufacturing (SSM) R&D projects for their region
  - Japan - METI and LSTC
  - US - NIST and the NSTC
  - EU Commission (Horizon Europe)
- SSM projects should include:
  1. Develop safe alternatives to PFAS-containing chemicals
  2. Develop safe alternatives to greenhouse gases
  3. Reduce water use, electricity use, and waste generation
- Gov't funding should be in the form of matching dollars directed by industry on SSM projects
- Projects could be contracted through SRC and/or SEMI, which can also provide a data sharing role and central coordination
- This (proposed) alliance will eliminating redundancies and can leveraging learnings between regions to drive a bigger agenda
- An industry-wide strategy is urgently needed to deal with 3-M's shut down of PFAS production and growing environmental regulations in areas with no known alternatives

BUILDING A PATH FORWARD

#SEMICONWest
Basic Research
• Expand human knowledge, not to invent. There is no obvious commercial value in basic research discoveries.

Applied Research
• Solve practical problems of the modern world.

Development
• Improve upon research for application towards a good or service.
  • High risk development.

Demo & Scale
• Certify that it can be produced and perform as expected.
  • Scale volumes to meet the market.

R&D Pipeline

Open, Good For All

Collaborative, Closed Community

Private, Defined Multi-party

Exclusive, Revenue Share

Commercial

Defense

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100% Univ.
University-led, Industry-informed
ESH
SRC’s “DARPA Programs”
Open, Good For All

100% Industry
Industry-led, University-informed
DARPA ERI
DoD Programs
Collaborative, Closed Community
Private, Defined Multi-party
Exclusive, Revenue Share

USG Funding

Commercial

Description

Defense

BUILDING A PATH FORWARD

#SEMICONWest
USG Funding

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Description

University-led, Industry-informed
- SRC’s “DARPA Programs”
  - Open, Good For All

Industry-led, University-informed
- DARPA ERI
  - Collaborative, Closed Community

DoD Programs
- Private, Defined Multi-party
  - Exclusive, Revenue Share

Open, Good For All

Collaborative, Closed Community

Private, Defined Multi-party

Exclusive, Revenue Share

100% Univ.

100% Industry

SSM w/ SRC, SEMI, and NSTC Research
Engage the Next Generation!

We need an aspirational new narrative that ignites the next generation of talent. Help Scholars see we have hard yet interesting problems that can’t be solved without them. Drive holistic, optimal solutions in HW/SW through interlocked multidisciplinary research. Convey to scholars that opportunities are abound for the next 20-30 years. Create industrial relationships and internship experiences that provide insight into SOTA*. We need an aspirational new narrative that ignites the next generation of talent.

*SOTA = State of the Art
THERE IS NO PLANET B!
SRC'S CALL TO ACTION

• To meet the needs of SRC's members and the industry we serve, SRC will continue to:
  • Invest in our **Three Pillars** (Prosperity, People, and the Planet) and
  • Invest in **ESH** thru academic projects on measurements, abatement, and alternatives

• There is an opportunity to build upon our work, thru SSM that emphasizes:
  1. The development of **safe alternatives to PFAS-containing chemicals**
  2. The development of **safe alternatives to greenhouse gasses**
  3. The **reduction** of water use, electricity use, and waste generation

• SSM must be a **partnership** that funds/engages all parts of the ecosystem
• Regional gov’ts are needed to help industry **jump-start** a collective commitment to the R&D of solutions that are important to different stakeholders

• We must provide **sufficient time** to identify and qualify suitable replacements
• SSM requires **sizeable investments, goal clarity**, and a **sense of shared urgency**
THANK YOU

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Nov’ 20 - Newly-Announced $3.4 Billion Plan Aims to Stimulate US Semiconductor R&D

https://www.src.org/about/decadal-plan/
"SRC has done a great job with their Decadal Plan to highlight this issue....of course it's not just the energy used, it's the impact on Planet Earth."
INTERIM SUMMARY – SUBJECT TO CHANGE