Dynamic Range-enhanced Electronics and Materials (DREaM)

Daniel S. Green
U.S. Defense Advanced Research Projects Agency (DARPA)

DREaM Proposers Day
Arlington, VA

March 29, 2017
Ground Rules

Purpose of this meeting:
• Discuss program objectives and structure.

After BAA published and until the deadline for receipt of proposals
• Open communications between proposers and the program manager are encouraged.
• But: Information given to one proposer must be available to all proposers.
• The best way to get a question answered is to email it, and to retrieve your answer from the Questions and Answers list via the MTO solicitations website.
• Note that any question that contains distribution restrictions, such as ‘company proprietary’, will not be answered.

Questions:
DREAM-BAA@darpa.mil
Welcome to the DREaM Proposers Day

- 08:30-09:00: Registration
- 09:00-09:05: Security Brief
- 09:05-09:15: Bill Chappell - Opening Remarks
- 09:15-09:45: Dan Green - DREaM Program
- 09:45-11:15: Presentations
  - MIT Lincoln Lab – Mark Hollis
  - UC Santa Barbara – Susanne Stemmer
  - Carbonics – Chris Rutherglen
  - Air Force Research Labs – Gregg Jessen
  - MIT – Tomas Palacios
  - Michigan State University – John Albrecht
  - Naval Research Laboratory – David Meyer
- 11:15-11:30: Break
- 11:30-12:00: Contracting
- 12:00-13:00: Q&A/Concluding Remarks
Dr. Daniel Green

DREaM Program Manager
What is DREaM?

DREaM will exploit **new materials and novel device structures** to create **RF transistors** that operate in a complex, **mm-Wave** spectrum.

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**Materials**

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Density (g/cm³)</th>
<th>Molar Mass (g/mol)</th>
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<tbody>
<tr>
<td>Al</td>
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<td>13</td>
<td>2.70</td>
<td>26.98</td>
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<tr>
<td>Si</td>
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<td>14</td>
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<tr>
<td>Sb</td>
<td>Sb</td>
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<td>6.69</td>
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<tr>
<td>Te</td>
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<td>7.22</td>
<td>127.60</td>
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<tr>
<td>In</td>
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<td>49</td>
<td>7.31</td>
<td>114.82</td>
</tr>
<tr>
<td>Sn</td>
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<td>Sb</td>
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<td>Bi</td>
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<td>64</td>
<td>8.59</td>
<td>157.25</td>
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</table>

**Power Density**

- $P_{out}$ (dBm), $G_r$ (dB)
- $P_{in}$ (dBm)

**Linearity**

- $P_{out}$ (dBm)
- Frequency

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DREaM transistors will transmit and receive complex EM signals of the future.
DREaM is a fundamental technology investment

Early Transistor Research

MI MlC Program

GaAs (1W/mm)

WBGS-RF Program

GaN (5W/mm)

DREaM FET (20W/mm)

DREaM power density will enable high power apertures in small form factors
Power density possible with new materials and devices

 Emerging materials

 Device Engineering

 ~10X higher charge density than GaN HEMT!

 3X higher power density (6.71 W/mm) at 94GHz!


Wienecke et al., 2016 74th Annual Device Research Conference (DRC), 1-2.

Materials and device concepts emerging to enable pushing high power density
DREaM recognizes the emergence of receive

**Linearity Metric**

- **1990**: MiM IC Program
- **2000**: GaAs (1W/mm)
- **2010**: WBGS-RF Program
- **Today**: GaN (5W/mm)
- **2020**: DREaM FET (20W/mm)
- **2030**: DREaM will drive system capabilities in new directions

**Early Transistor Research**

- **TRL 1**
- **TRL 7**

**Technical Area #1**

- **Power Density (W/mm)**
  - **Si**: 1000
  - **GaAs**: 100
  - **GaN**: 10
  - **TA1**: 1
  - **TA2**: 1

**Technical Area #2**

- **PA**
- **Rx**
- **Tx**
- **Antenna**

**DREaM**

- **Maturation/Future Systems**

**Timeline**

- **1997**: AN/APG-77
- **1998**: F-117 Nighthawk
- **2008**: DARPA AN/TRP-2 Radar
- **2013**: Zumwalt Class Destroyer
- **2015**: AN/SPY-3 Radar with GaN
- **2016**: AMDR
- **2018**: Space Fence
- **2020**: NGJ

**Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)**
Thinking about dynamic range

Amplifier Impact

Linearity Signal Impact

Two-Frequency Signal

Today

Desired signals

OIP3

RF Power

Frequency

Unwanted IM3

After DREaM

RF Power

Frequency

High linearity required for detection of weak signals
Breaking the “10 dB rule” will alter the SWAP and performance trade space.
Gap at millimeter wave

There are no alternative solutions in mm-Wave

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
Linearity benefits realized in prototype devices

Intrinsic linear device

Carbon nanotube FET has improved transfer function

M. Schroter et al., *IEEE J. Electron Devices Society*, vol. 1, pp. 9

New fabrication process

FINFET approach improves transfer function

D. S. Lee et al., *IEEE Electron Dev Lett*, vol. 34 pp. 969

Nanoscale devices and materials show potential for linearity gains

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
### DREaM Program Plan & Metrics: Tech Area #1

**Metric** | **Today** | **Phase I** | **Phase II** | **Phase III**
--- | --- | --- | --- | ---
Center Frequency (GHz) | 30 |

#### TA1 High Power Track

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Power Amplifier Focus (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min CW Power Density (b) (W/mm or equivalent)</td>
<td>~4</td>
</tr>
<tr>
<td>Min CW Power (Watt) (b)(c)</td>
<td>1~2</td>
</tr>
<tr>
<td>Min OIP3/P_Dc (dB) up to 10 dB backoff from peak PAE</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Min PAE (%) (b)</td>
<td>35</td>
</tr>
</tbody>
</table>

- CW testing required for Phase I metrics
- Phases II and III, government will assess with pulsed measurements with a duty cycle of 30%, pulse width of 15 ms, and CW RF power applied while the device is in the on state

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(a) All TA1 and TA2 device metrics will be measured in matched environment at 30 GHz. Additional on-wafer small-signal s-parameter measurements are required to demonstrate DREaM devices are capable of supporting 5% bandwidth operation around 30 GHz.

(b) $P_{out}$ (W/mm and in W) and PAE must be achieved simultaneously. CW measurement required for Phase I only.

(c) Fixed baseplate temperature ($\geq 25^\circ C$), with either air cooling or no external cooling
## DREaM Program Plan & Metrics: Tech Area #2

### Phase 1 (24 mo.)
- Material & device proof of concept

### Phase 2 (18 mo.)
- Transistor scaling

### Phase 3 (18 mo.)
- DREaM transistor realization

### Test Condition

<table>
<thead>
<tr>
<th>Metric</th>
<th>Today</th>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Frequency (GHz)</td>
<td></td>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td><strong>Test Condition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max NF (dB)</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Min Gain (dB)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Min Linear P_{out} (dBm)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Min OIP3/P_{DC} (dB) up to 0 dBm P_{out}</td>
<td>&lt;10</td>
<td>20</td>
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(a) All TA1 and TA2 device metrics will be measured in matched environment at 30 GHz. Additional on-wafer small-signal s-parameter measurements are required to demonstrate DREaM devices are capable of supporting 5% bandwidth operation around 30 GHz.
**Step 1:** Plot from the 2-tone test, $P_{out,f_0}$, IM3, PAE and $P_{DC}$ vs $P_{in}$.
Step 1: Plot from the 2-tone test, $P_{out, f_0}$, IM3, PAE and $P_{DC}$ vs $P_{in}$.

Step 2: Locate peak PAE and draw a vertical line 10 dB backed-off from peak PAE.
OIP3/$P_{DC}$ Metric Testing Methodology

Step 1: Plot from the 2-tone test, $P_{out,f_0}$, IM3, PAE and $P_{DC}$ vs $P_{in}$.

Step 2: Locate peak PAE and draw a vertical line 10 dB backed-off from peak PAE.

Step 3: For the $P_{in}$ of interest, draw a horizontal line 10 dB above $P_{DC}$.
**OIP3/P_{DC} Metric Testing Methodology**

---

**Step 1:** Plot from the 2-tone test, \( P_{out,f_0}, \) IM3, PAE and \( P_{DC} \) vs \( P_{in} \)

**Step 2:** Locate peak PAE and draw a vertical line 10 dB backed-off from peak PAE

**Step 3:** For the \( P_{in} \) of interest, draw a horizontal line 10 dB above \( P_{DC} \)

**Step 4:** Extrapolate \( P_{out,f_0} \) from its linear region (slope = 1) until it crosses the horizontal line drawn in Step 3
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Step 4: Extrapolate \( P_{out,f_0} \) from its linear region (slope = 1) until it crosses the horizontal line drawn in Step 3

Step 5: Draw a line with a 3:1 slope that goes through the crossing point of the lines in Steps 3 and 4.
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Step 4: Extrapolate $P_{out,f_0}$ from its linear region (slope = 1) until it crosses the horizontal line drawn in Step 3

Step 5: Draw a line with a 3:1 slope that goes through the crossing point of the lines in Steps 3 and 4.

Step 6: If IM3 is below the line drawn in Step 5, then the device meets the metric at that $P_{in}$ level
**OIP3/P\(_{DC}\) Metric Testing Methodology: TA2**

**Step 1:** Plot from the 2-tone test, \(P_{out,f_0}\), IM3, PAE and \(P_{DC}\) vs \(P_{in}\)

**Step 2:** Locate \(P_{out,f_0} = 0\; \text{dBm}\) and draw a vertical line through it

**Step 3:** For the \(P_{in}\) of interest, draw a horizontal line 20, 25, or 30 dB above \(P_{DC}\)

**Step 4:** Extrapolate \(P_{out,f_0}\) from its linear region (slope = 1) until it crosses the horizontal line drawn in Step 3

**Step 5:** Draw a line with a 3:1 slope that goes through the crossing point of the lines in Steps 3 and 4.

**Step 6:** If IM3 is below the line drawn in Step 5, then the device meets the metric at that \(P_{in}\) level

**Noise Floor + Noise Figure**

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# DREaM Program Plan & Metrics Summary

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<th>Phase II</th>
<th>Phase III</th>
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<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA1 High Power Track</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>&lt;10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Min PAE (%)</td>
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<td>40</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td><strong>Test Condition</strong></td>
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<td>TA2 High Linearity Track</td>
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<tr>
<td>Max NF (dB)</td>
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<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Min Linear P_{out} (dBm)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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(b) P_{out} (W/mm and in W) and PAE must be achieved simultaneously. CW measurement required for Phase I only.

(c) Fixed baseplate temperature (≥ 25°C), with either air cooling or no external cooling.

- Proposers may propose to both TA1 and TA2 in a single proposal if there is a clear rationale.
DREaM Program Timeline

FY17 | FY18 | FY19 | FY20 | FY21 | FY22

Material & device proof of concept

Phase 1 (24 mo.)

- Device delivers starting at Month 6 of Phase I

Phase 2 (18 mo.)

- Transistor scaling

Phase 3 (18 mo.)

- DREaM transistor realization

- Devices Meet Phase II Metrics

- Devices Meet Phase III Metrics

No Circuits!!!
BAA Highlights / Program Deliverables

- **BAA Highlights**
  - Focus on intrinsic transistor performance (page 8)
  - Additional intermediate milestones to mitigate risk (page 11)
  - Proposed device should have viable path to Phase III goals (page 12)

- **Deliverable Highlights**
  - Technical and Financial Reports (both monthly)
    - Quarterly TIM
    - Semi-annual PI review
  - Prototype Devices
    - Regular quarterly deliveries starting after month 6
    - Set of 10 testable devices per delivery
    - Packaging as necessary (not required if testable on wafer)
    - Testplan required
Non-DREaM Developments

Technology NOT germane to DREaM:
- Linearity improvements through circuit techniques
- Thermal solutions not tied to intrinsic device enhancements

Focus is on making the device fundamentally linear and intrinsically higher power!
What do we plan to spend? and When?

- **Anticipated Funding Available for Award:** DARPA anticipates a funding level of approximately $40M for the DREaM program.
- **Anticipated individual awards** – Multiple awards in each Technical Area are anticipated.
- **Anticipated funding type** - 6.2
- **Types of instruments that may be awarded** – Procurement contract, grant, cooperative agreement or other transaction.

### Important Dates

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
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<tbody>
<tr>
<td>Proposers Day</td>
<td>29-Mar-2017</td>
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<tr>
<td>BAA Release</td>
<td>28-Mar-2017</td>
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<td>FAQ Deadline</td>
<td>10-May-2017</td>
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<td>Proposals Due</td>
<td>24-May-2017</td>
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<td>Program Kick-Off</td>
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DREaM
Dynamic Range-enhanced Electronics and Materials

DARPA

www.darpa.mil

- Proposers Day: March 29, 2017
- FAQ Submission Deadline: May 10, 2017
- Proposal Due Date: May 24, 2017
- BAA Coordinator: DREAM-BAA@darpa.mil
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