Massachusetts Institute of Technology

How Integration will Enable The Light Bulb of the Future

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The Light Bulb of the Future…

Applications:

- Communications hub
- Presence sensor
- Alarm
- Wireless power transmitter
- Smart thermostat
- Environmental sensor

- Lighting

Constrain: Cost

Solution: Integration

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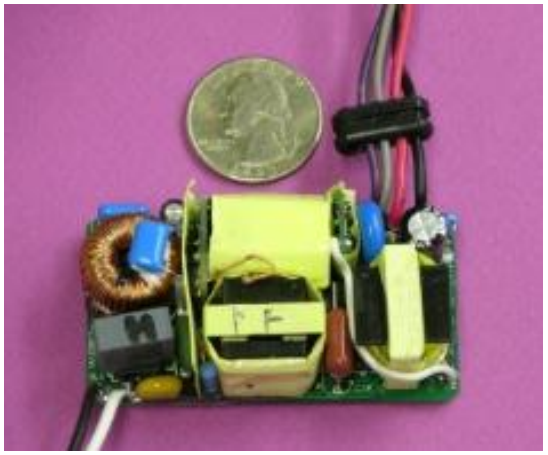
Can we first integrate the power supply?



~ 10-100x reduction in size with full integration

~ 3x reduction in energy loss

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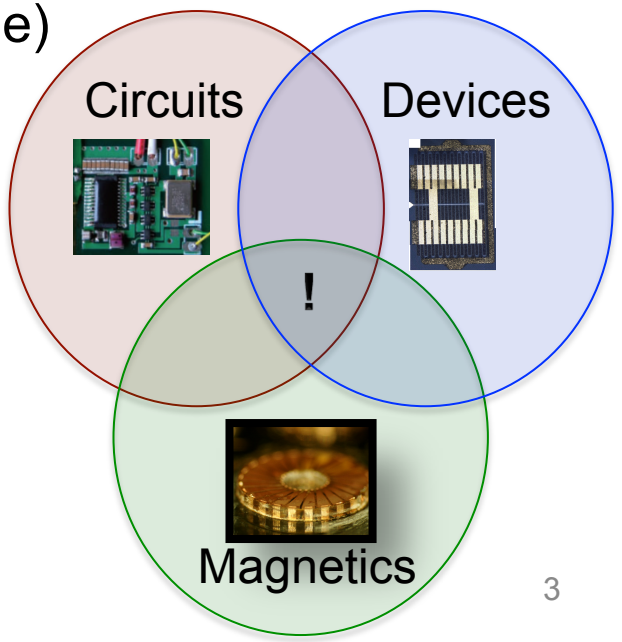
ARPA-E ADEPT Program

- **Target: Miniaturization (>10x reduction in size)**
  - Radical improvements in the size of power grid-scale voltage (>100 V) power electronics at moderate power levels (e.g., 10-100 W)
- **Focus: Greatly increased frequencies (10-100x)**
  - GaN-on-Si power devices (Design and reliability)
  - Integrated magnetics (μ-fabrication of cores and windings, new nanostructured magnetic materials for high frequency operation)
  - Circuit architectures (for high f, density, lifetime)
- **Additional advantage:**
  - Increase reliability in electrolytic-free circuit



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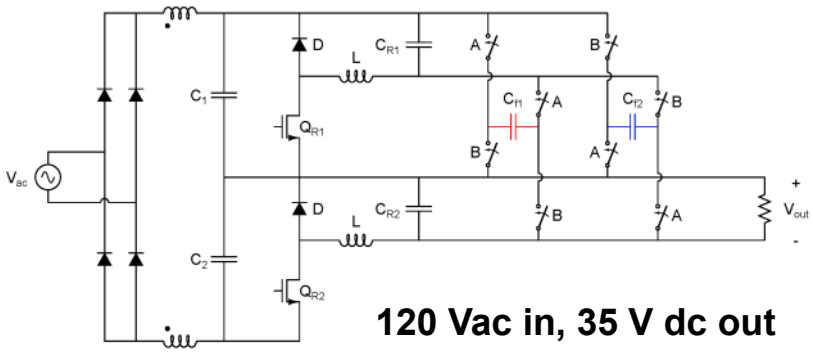
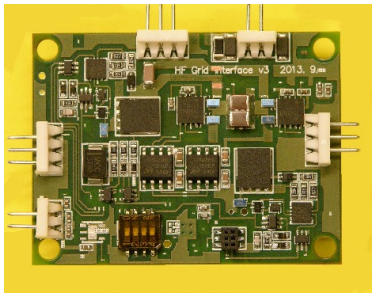
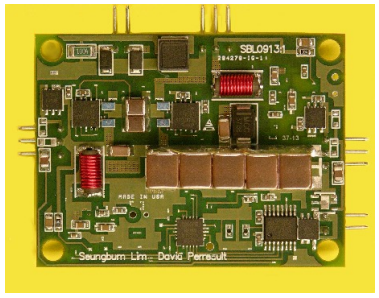
System Demo

- New circuit architecture for HF grid-interface conversion
  - Facilitates high frequency and miniaturized magnetics
  - High power factor *without* (unreliable) electrolytics
- Key targets achieved (>10x frequency, > 10x power density)



120 Vac in, 35 V dc out

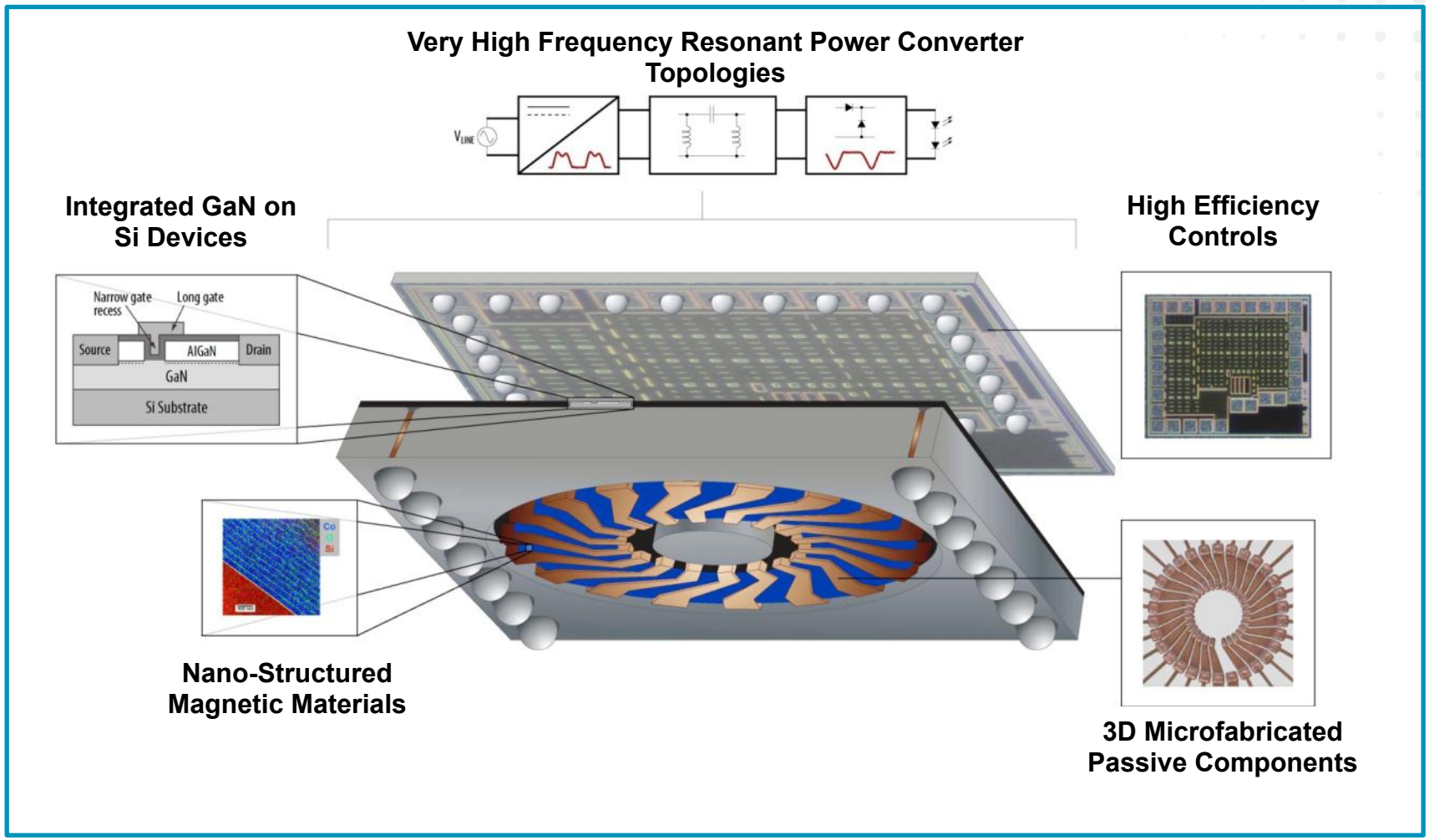




	Commercial	PowerChip
Efficiency	64 - 83 %	93 %
Switching Frequency	57 - 104 kHz	**5-10 MHz**
Power Factor	0.73-0.93	0.89
Power Density	< 5 W/in^3	**>50 W/in^3** (to 130 W/in^3)

Circuit design by Prof. Perreault @ MIT

ARPA-E ADEPT Future Integrated Power Module



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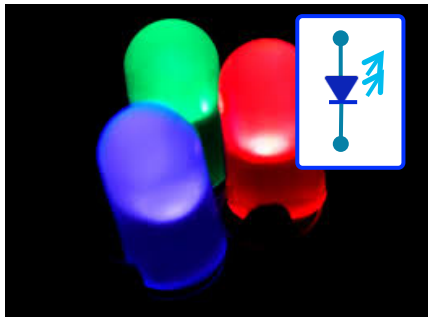
GaN LED and GaN Power Transistors

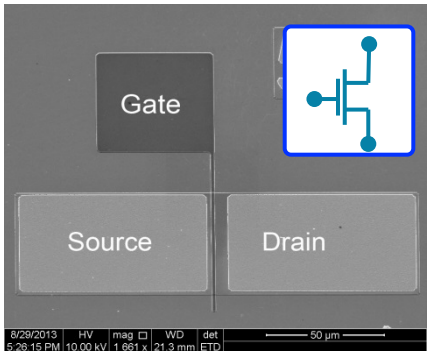
= 2 or 1 chips?

~30% of chip cost is due to packaging

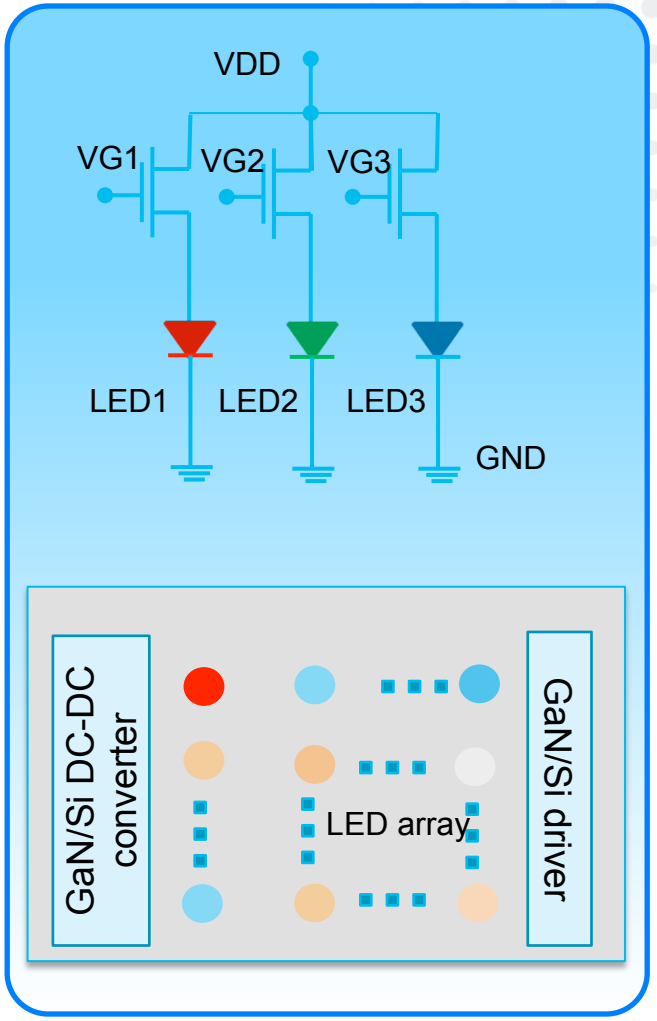
Increasing the level of integration even further…



GaN LEDs



GaN control and power electronics



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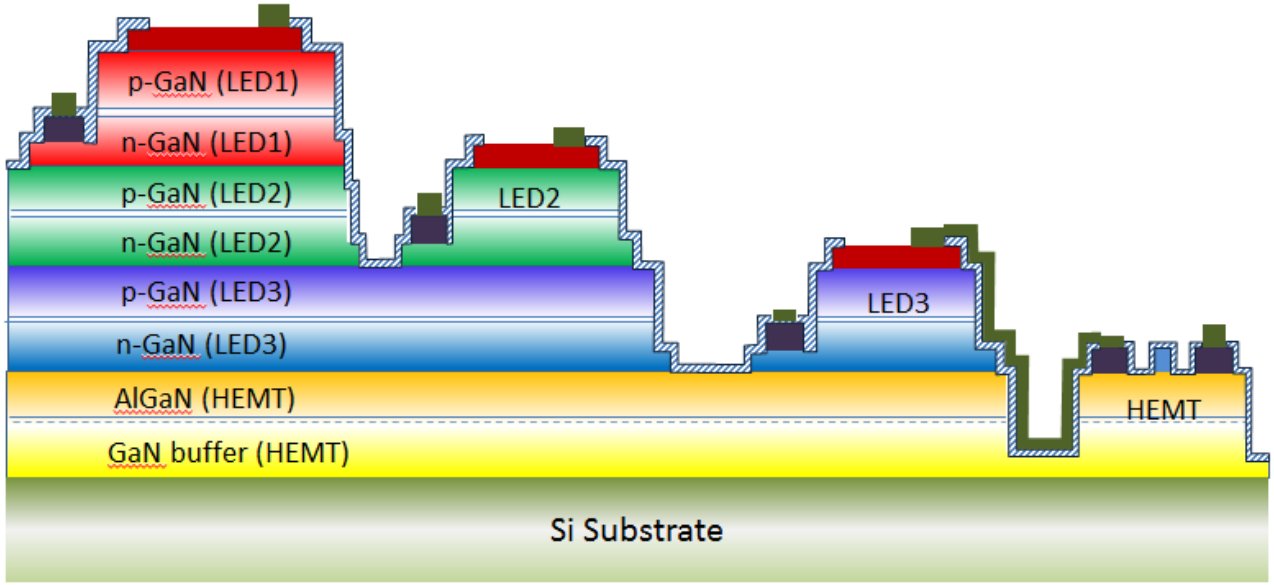
GaN Vertical LED-HEMT Integration



► **LED is on top of HEMT:**

- **p-GaN on top is easier to activate**
- **The LED's doping (if grown first) would make HEMT pinch-off difficult**

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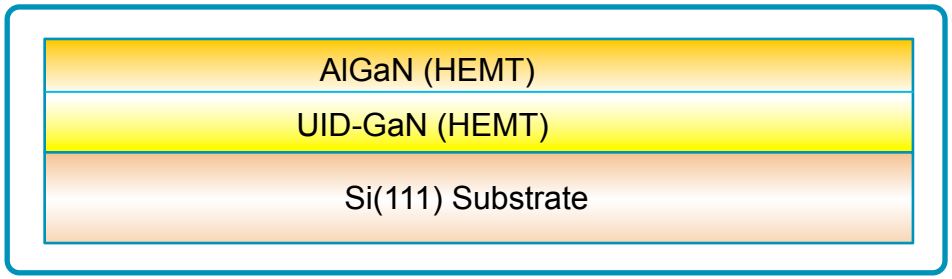
Process Flow for GaN LED-HEMT

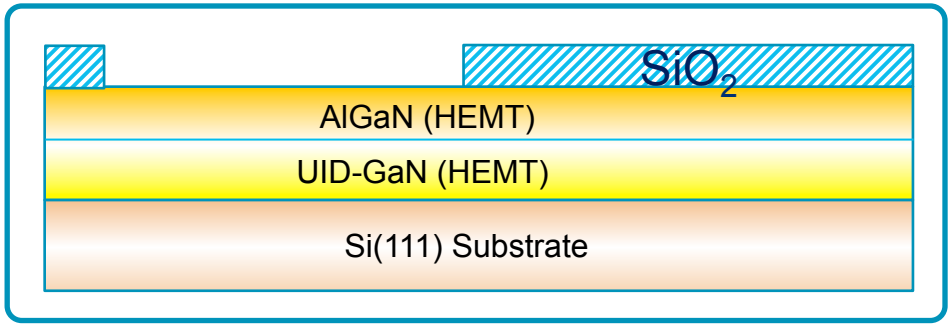
Integration 1

Start from: GaN HEMT on Si wafer (*from AIXTRON*)



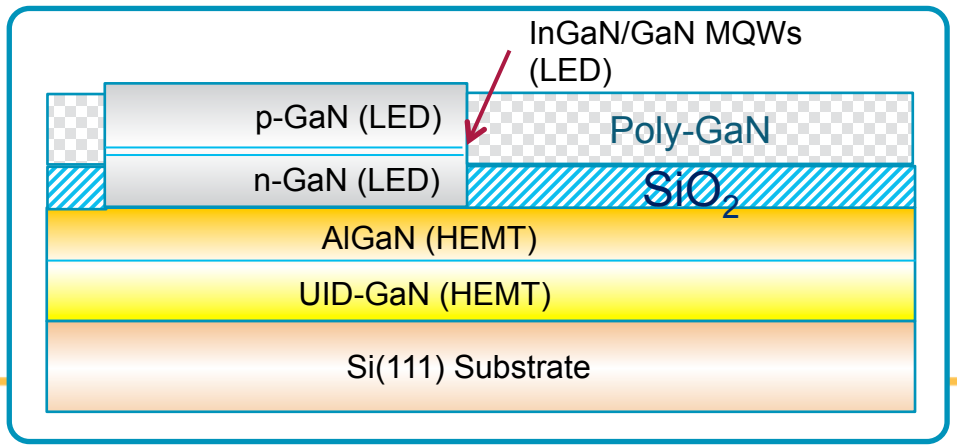
LED growth window formation

- PECVD SiO_2 on the whole wafer
- Lithography patterning
- SiO_2 etch and window opening



LED layers epi-growth

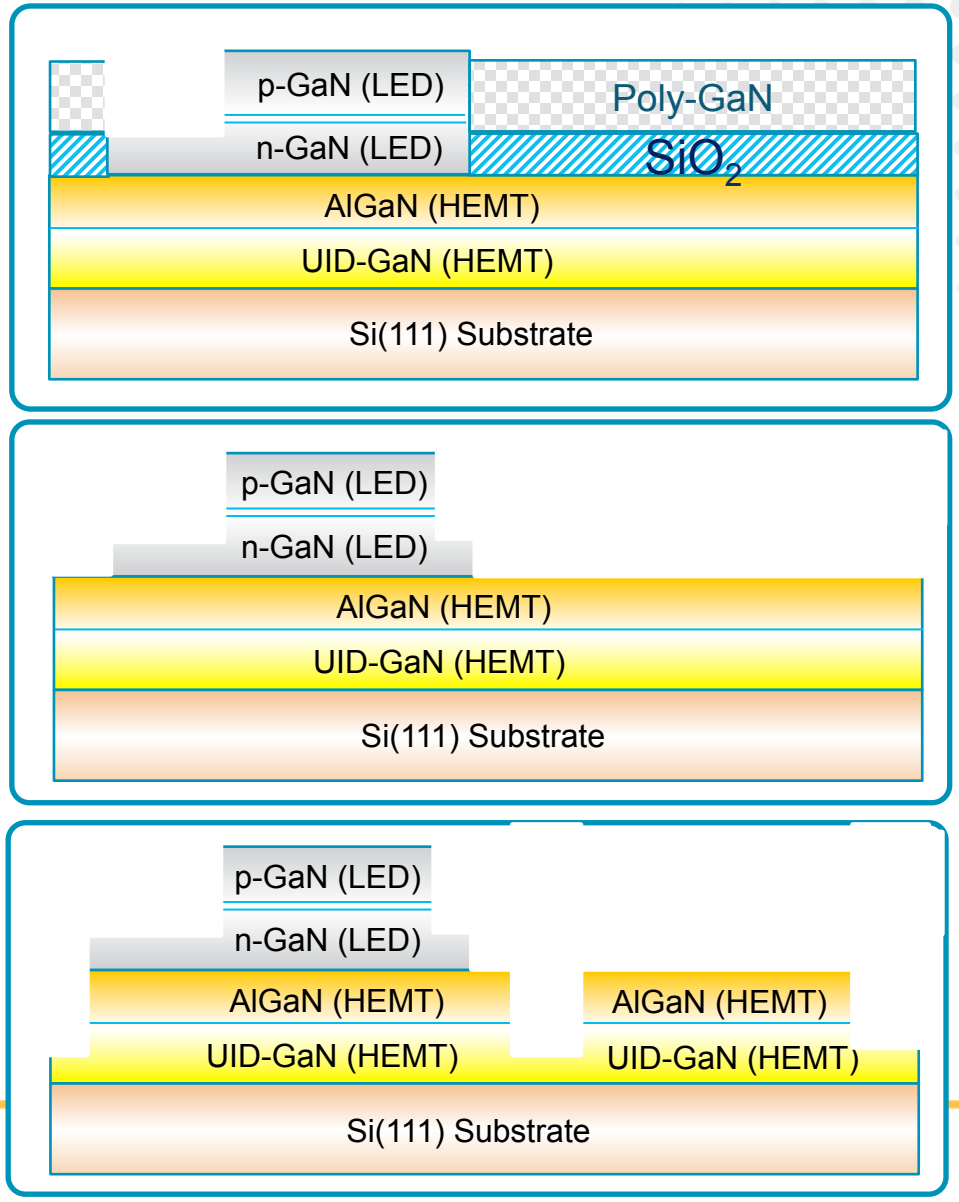
(By Li Zhang, Prof. Chua in NUS)



Process Flow for GaN LED-HEMT

Integration 2

- **p-electrode mesa etch**
  - Lithography
  - Plasma dry etch of p-GaN, QW and part of n-GaN layers
- **poly GaN/SiO_2 removal and LED mesa formation**
- **HEMT mesa isolation**
  - Lithography: HEMT mesa patterning
  - Plasma dry etch of HEMT barrier and part of channel layers



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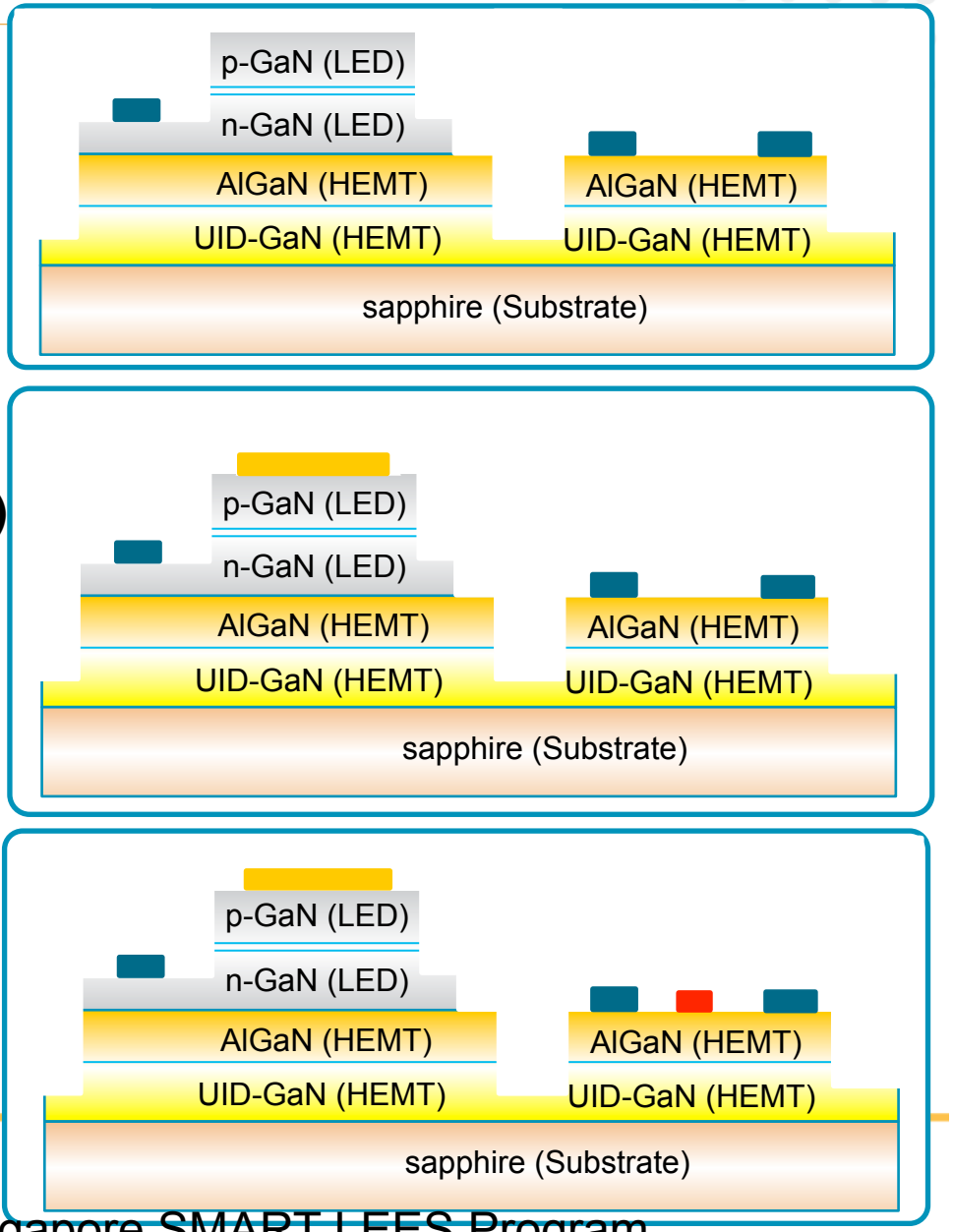
Process Flow for GaN LED-HEMT

Integration 3

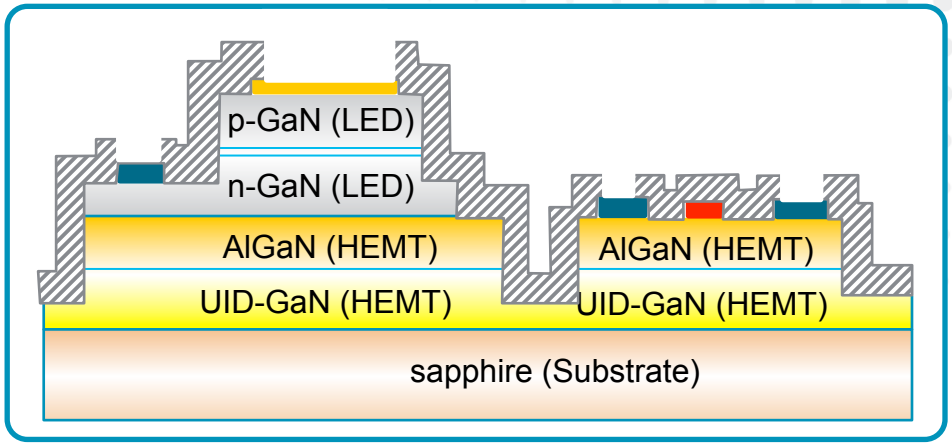
- **LED n-contact and HEMT ohmic contact**
  - Lithography: patterning
  - Metal deposition and lift-off (Ti/Al/Ni/Au)
  - Annealing
- **LED p-contact (Transparent Conducting Layer, TCL)**
  - Lithography: patterning
  - Metal deposition and lift-off (Ni/Au)
  - Annealing
- **HEMT gate formation**
  - Lithography: patterning
  - Metal deposition and lift-off (Ni/Au)

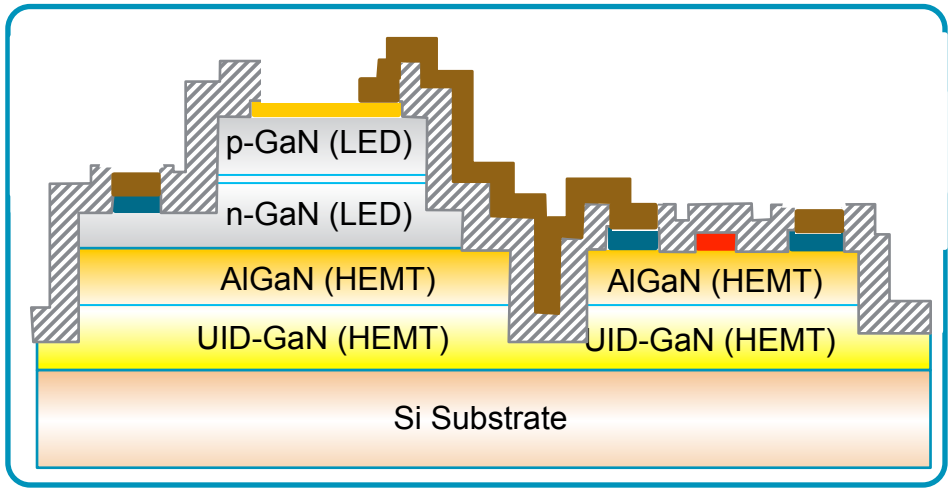


Process Flow for GaN LED-HEMT

Integration 4

- **Dielectric deposition and passivation**
  - PECVD SiN/SiO2 deposition
  - Lithography: patterning
  - SiN/SiO2 etch
- **Metal Interconnect**
  - Lithography: patterning
  - Metal deposition and lift-off (Ti/Au)





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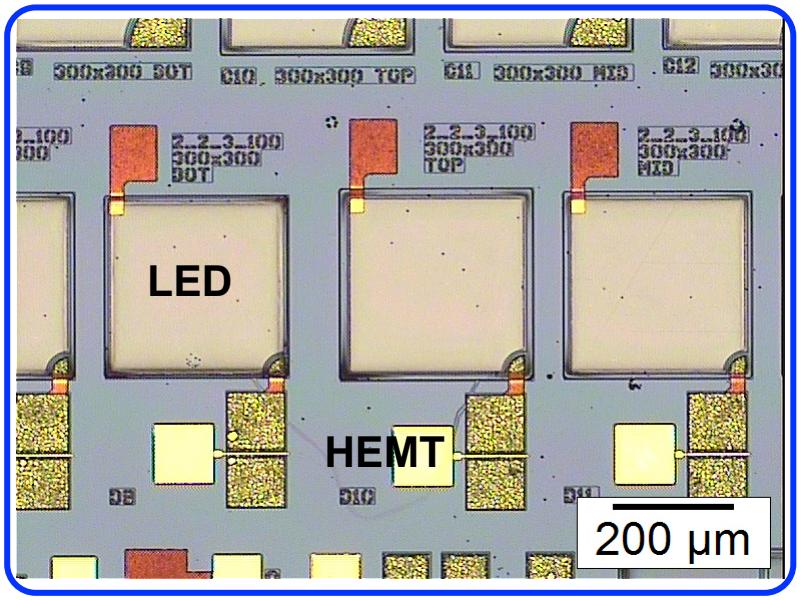
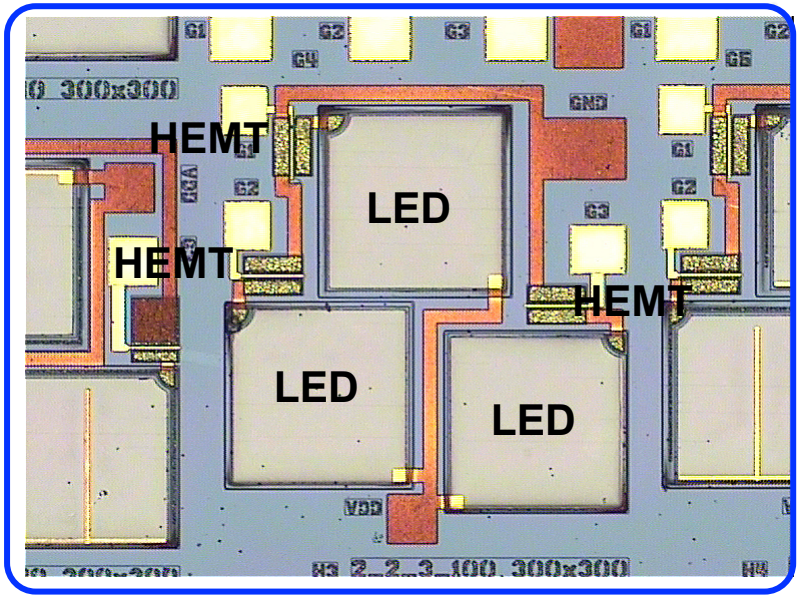
LED and HEMT Integration





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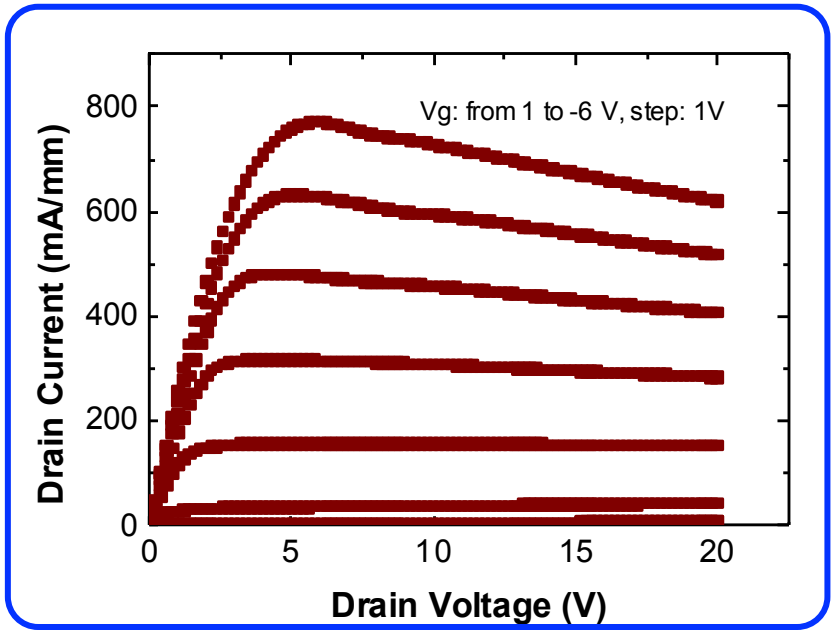
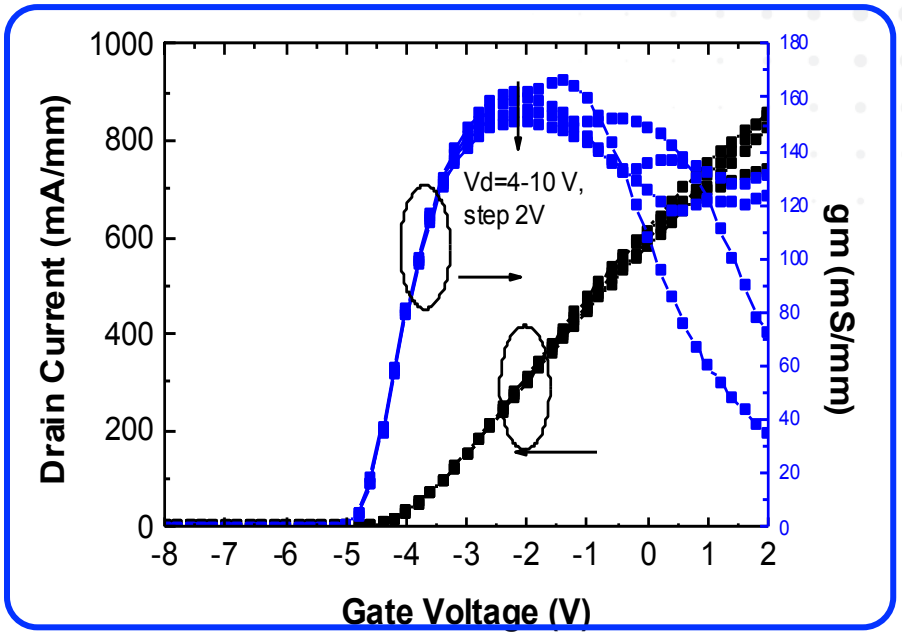
HEMT Characteristics on the LED-HEMT Wafer





Device dimensions:

Lsd=8.5 μm; Lg=2.5 μm

Main characteristics:

Idmax: 770 mA/mm (at Vg=1V); Ron: 3.55 Ω-mm

Gmmax: 166 mS/mm; Vth= - 4.04 V

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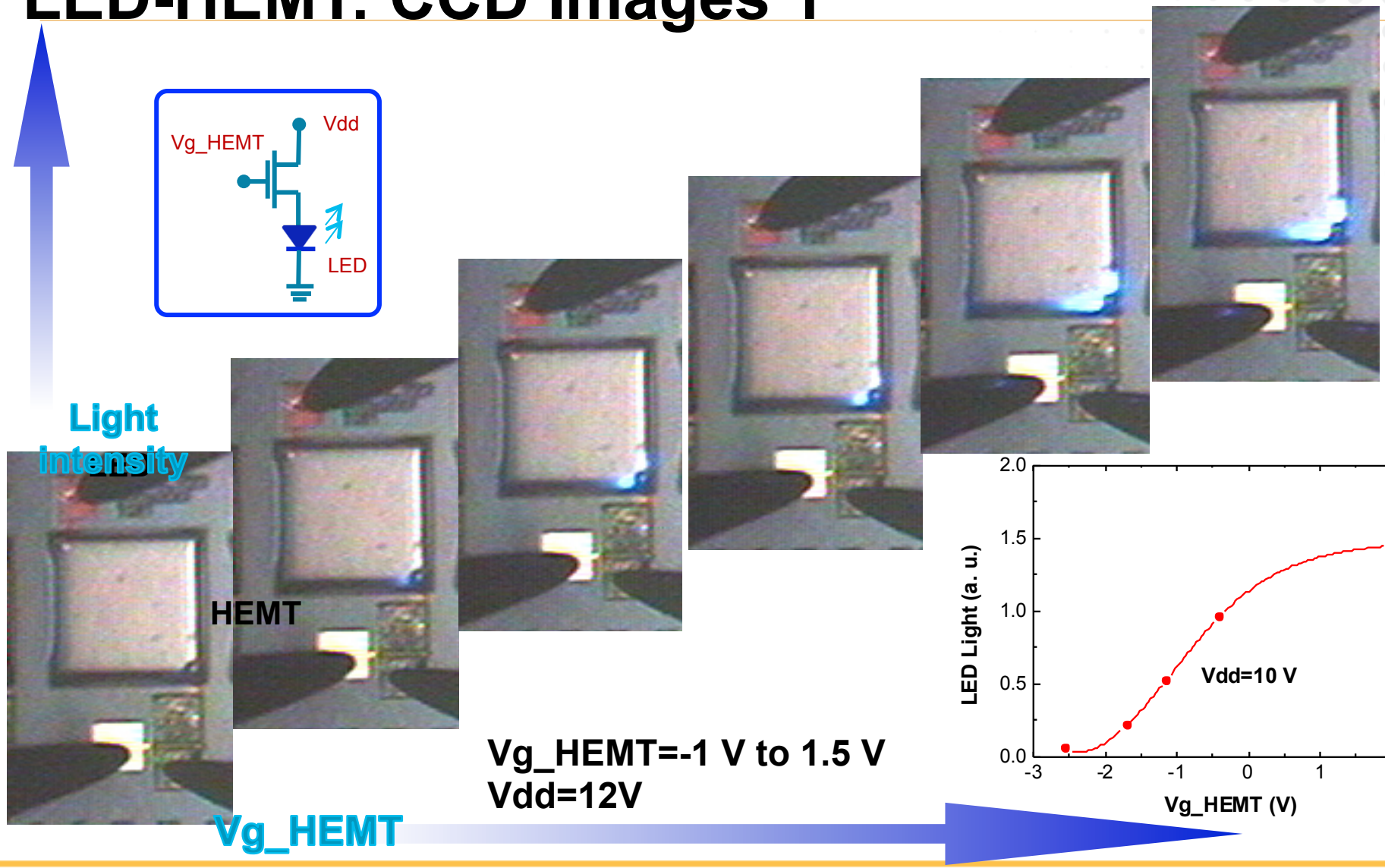
Optical Characteristics of the Integrated LED-HEMT: CCD Images 1



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Integrated GaN Lighting System?

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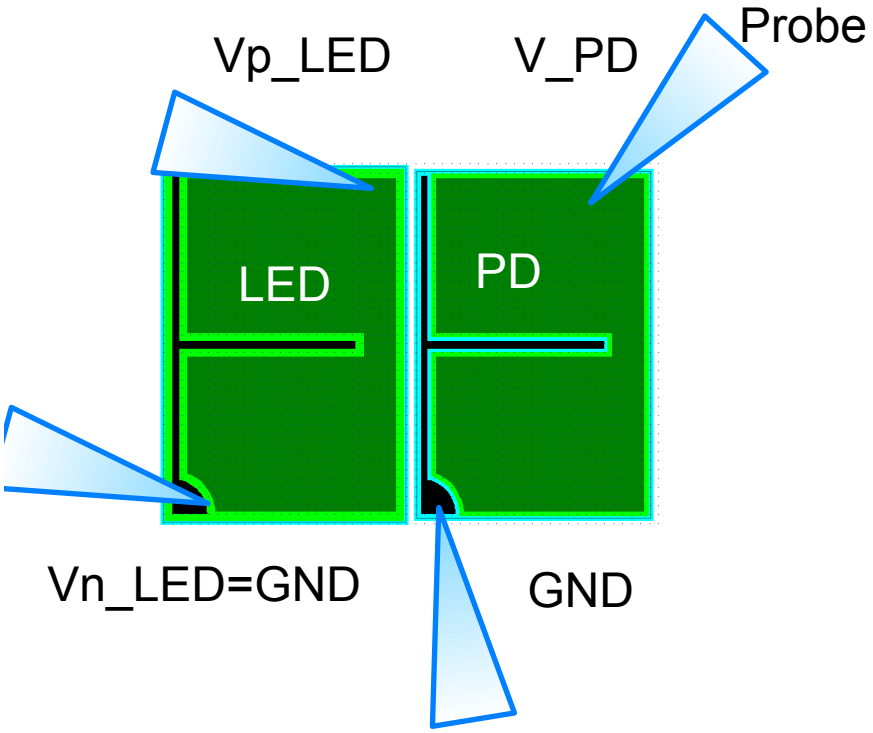
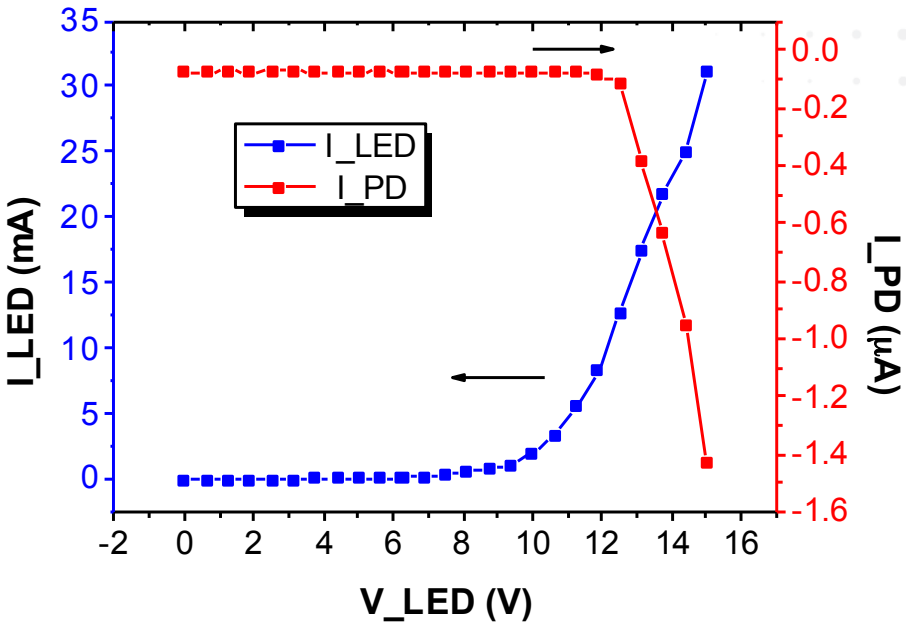
We can also integrate a Photodetector…





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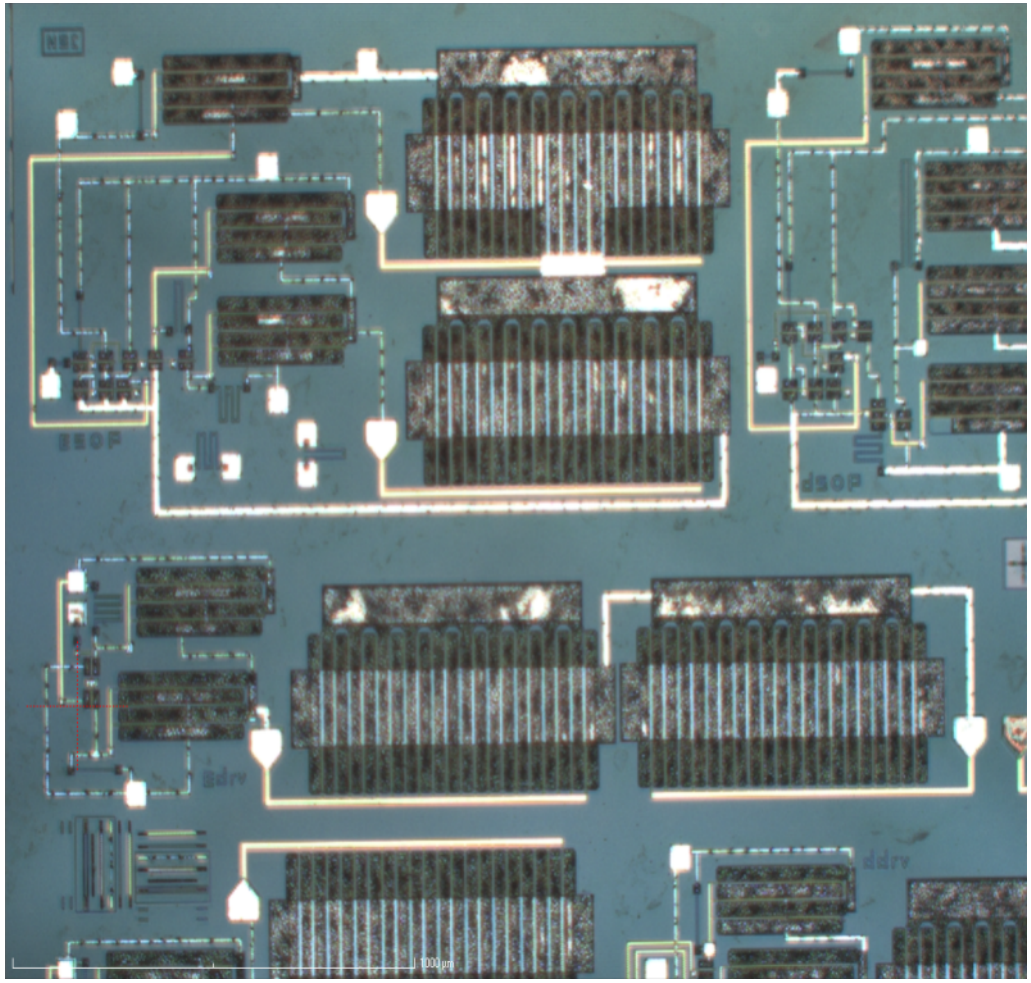
As well as more complex electronics…



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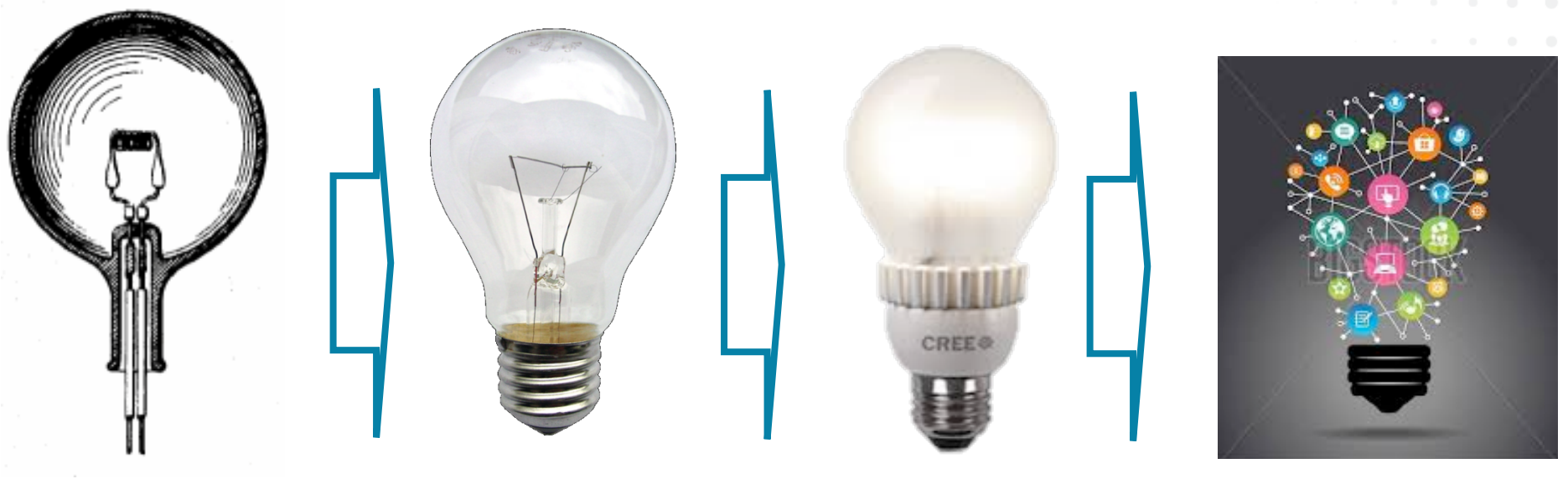
Summary… The light bulb of the future…



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Integration will be key to reach the right price target for the light bulb of the future.

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