MACOM™

Partners from RF to Light

MWJ: RF Energy Webinar
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Outline

Introduction

- MACOM Company Overview

RF Energy

- What is RF Energy?
- RF Energy Market Opportunities
- RF Energy Alliance
- Market Growth Estimates

Why GaN is a fit for RF Energy

- Technical Specs (Efficiency, Gain)
- GaN Technology: SiC vs Si Comparison
- LDMOS vs GaN Si

Plastic Packaging

- LDMOS/GaN SiC/GaN Si

RF Energy Application Highlights

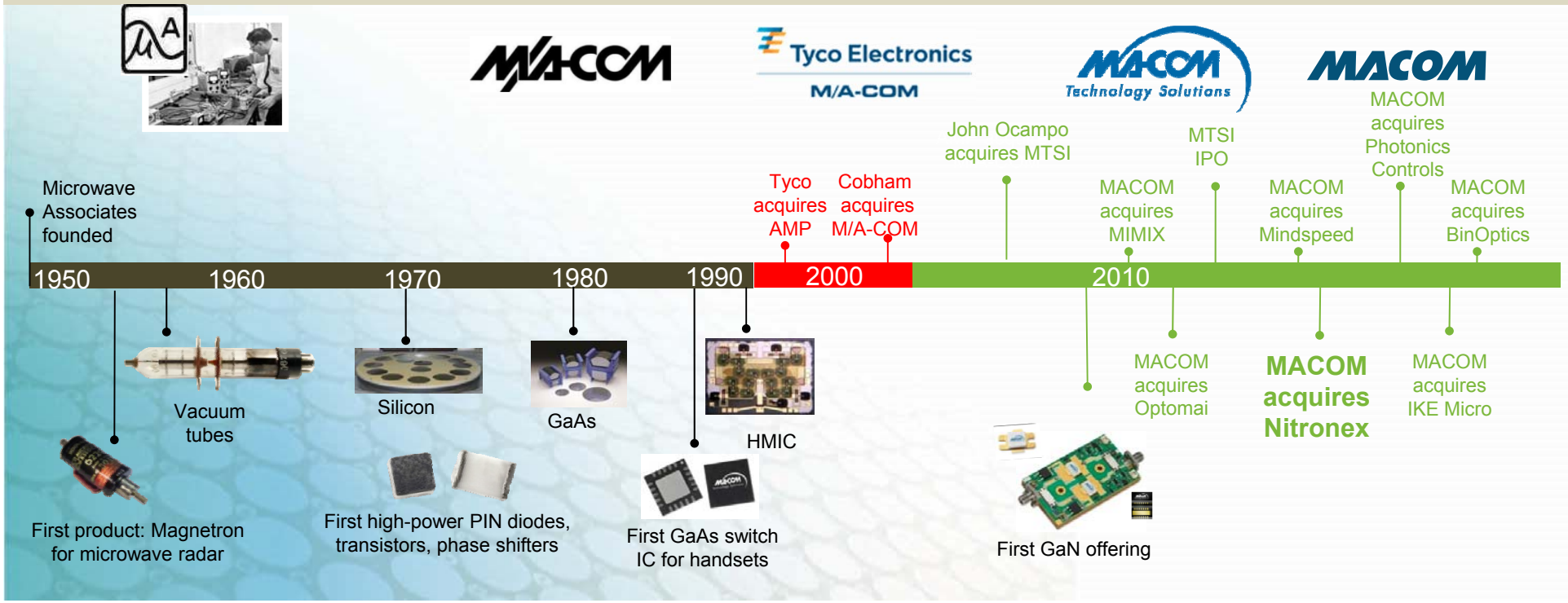
- Industrial Heating & Cooking
- Automotive Ignition
- Plasma Lighting
- Medical

Future of RF Energy

MACOM Company Overview

Provider of High-Performance Analog RF, µW, mmW and Photonic Solutions

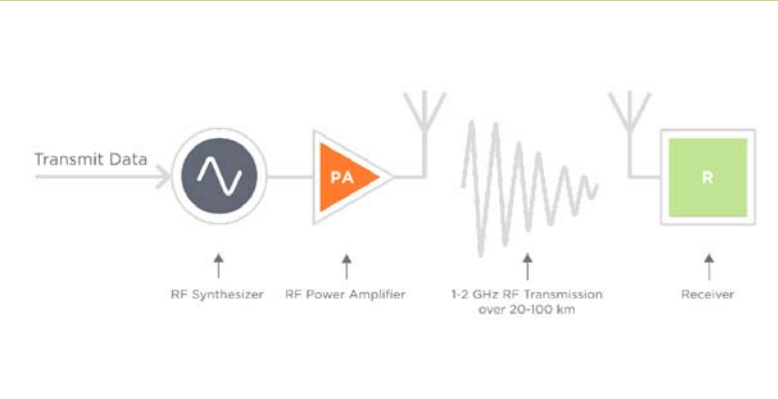
- Headquartered in Lowell Massachusetts
- 27 offices worldwide, 1101 employees
- $418 million of FY 2014 revenue
- Strong Patent and IP Position
- 6,000+ customers worldwide
- Global, multi-channel sales strategy
- 3,000+ products across 40 product lines
- 60 years of RF & Microwave History
- MACOM continues to invest in technologies – enabling RF Energy and other volume applications



What is RF Energy?

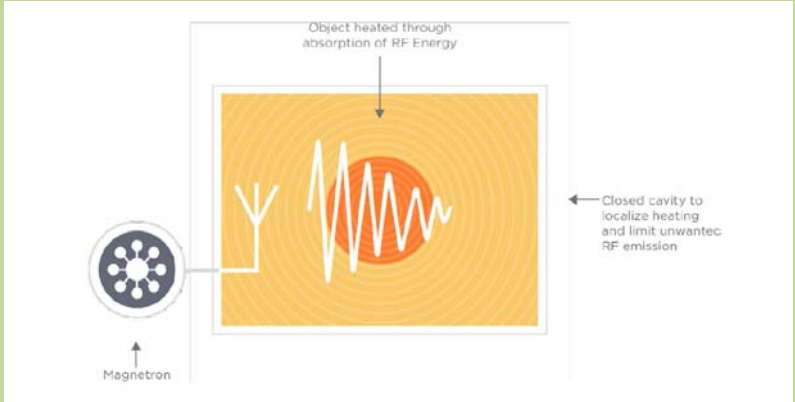
Classical RF Use:

Long-Distance Data Transmission

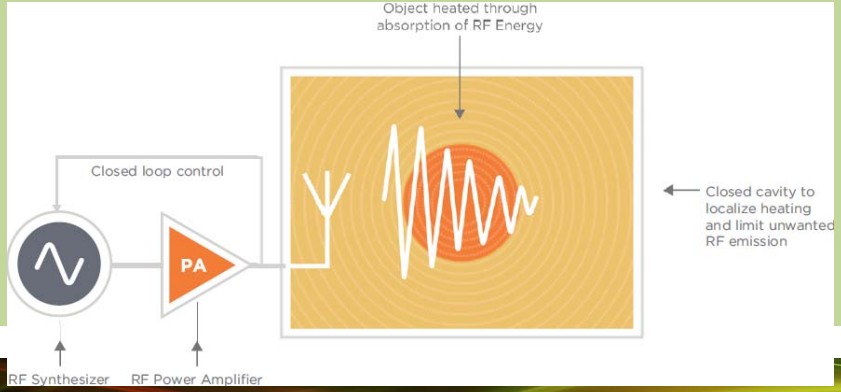


Classical RF Use:

Magnetron Drive for Local Heating



Solid State RF Energy:



Application Highlights




TRANSITIONING	EMERGING	CURRENT	POTENTIAL	MORE INNOVATIONS
• Cooking • Drying • Industrial Processing	• Industrial Lighting	• Ablation • MRI/NMR • Lasers	• Auto Ignition • Auto Lighting	
Benefits from better control, form factor, design freedom	Benefits from higher volume, better control, form factor	Benefits from higher volume, cost-efficiency, form factor	Benefits from standardization, reliability, control and form factor	

Market Opportunities




TRANSITIONING	EMERGING	CURRENT	POTENTIAL	MORE INNOVATIONS
• Cooking • Drying • Industrial Processing	• Industrial Lighting	• Ablation • MRI/NMR • Lasers	• Auto Ignition • Auto Lighting	
> 70 million microwaves per year (global) > 10.9 million dryers per year (US + EU)	High-bay luminaires market alone will reach $17B (2017)	> 2000 MRIs per year Global ablation CAGR of 9.6% (2014 to 2019) US ablation market reach of $295M (2017)	> 87 million automobiles per year	

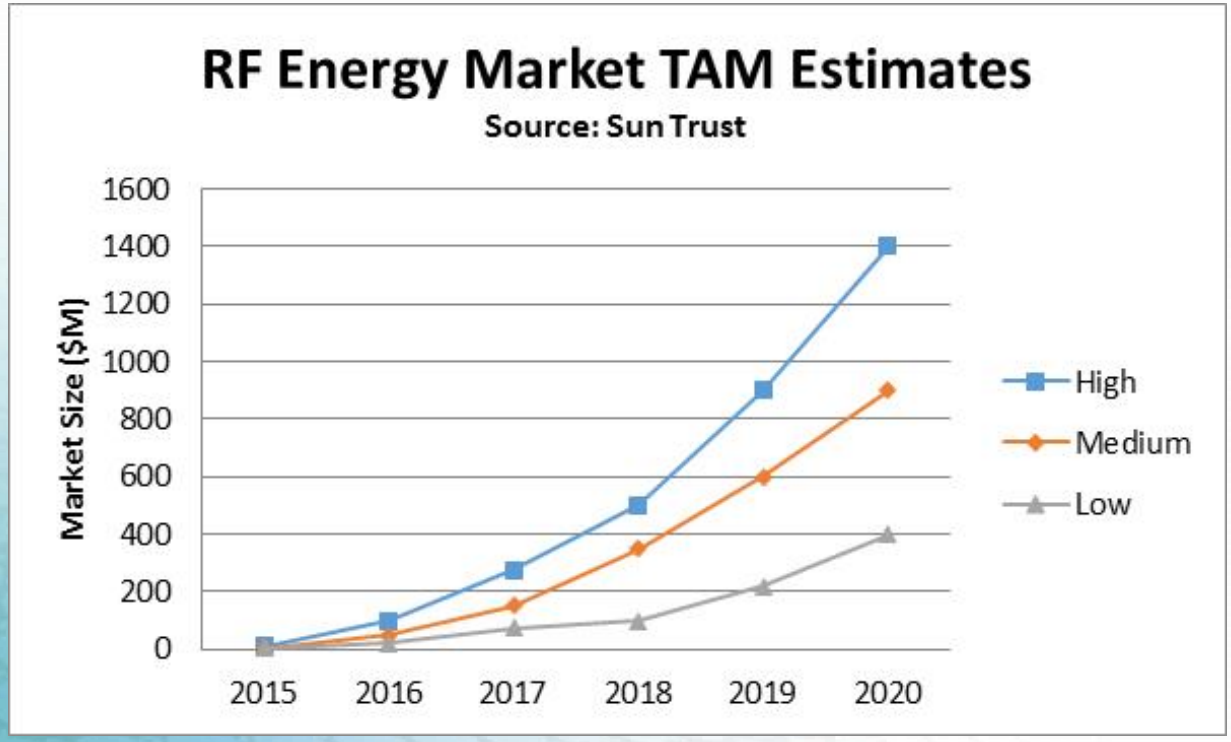
RFENERGY ALLIANCE

Standardizing solid-state RF energy components, modules and application interfaces to:

- Reduce system cost
- Minimize design complexity
- Ease application integration
- Increase market adoption & growth

RF Energy Market Growth Estimates

RF Energy Market forecasted to exceed $1B in 5 years (SunTrust market report)



Key RF Energy Markets:

- RF Energy Transfer
- Solid State Heating
- Plasma Lighting
- Spark Plug Ignition
- RF Heating/Drying
- Medical (Tumors)

Why Gallium Nitride on Silicon?

Semiconductor Property Comparison

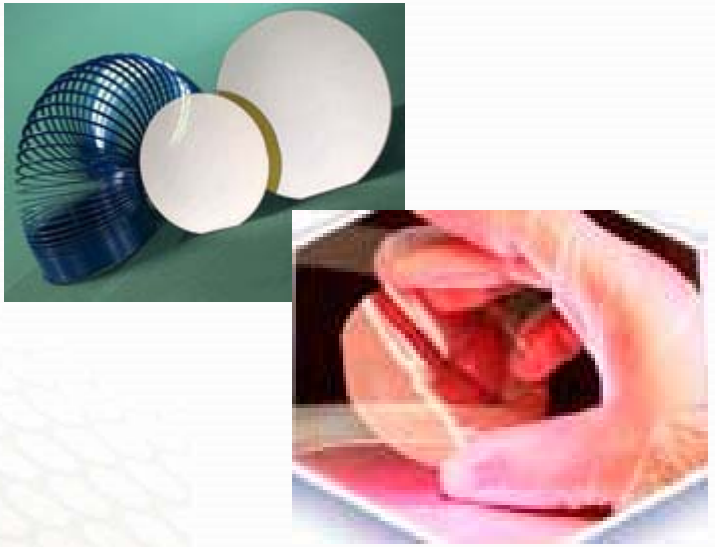
Property	Si LDMOS	GaN/SiC	GaN/Si
Power Density			
Ruggedness			
Cost			
Efficiency			
High volume Manufacturability			
Cost/Power density/Ruggedness/ Efficiency FOM			

Why GaN? Substrate Materials Technology Drives Cost

Device Technology	Substrate Technology	Growth Temp/Rate	Size	Crystal Defect Density	Industry Volume	$/in^2
GaN on SiC	SI-SiC	2000°C 150um / hr	3" - 6"	Present - Increases with Wafer Size	1 X	1 X
GaN on Si	Silicon	1400°C 7.62cm / hr	4" – 12"	None	10^6 X	10^{-3} – 10^{-4} X

Silicon World

Silicon Carbide World



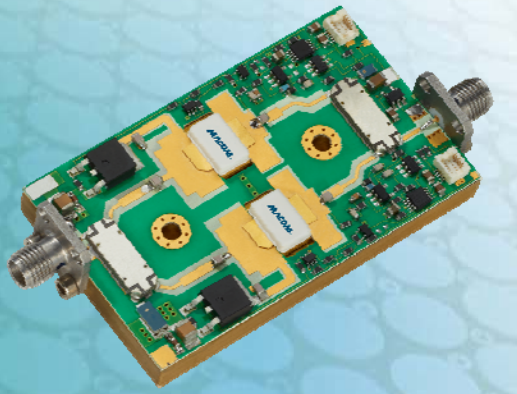
MACOM's Plastic Packaging and Module Capabilities

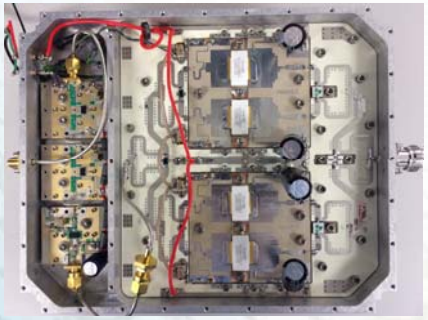
Plastic Packaging

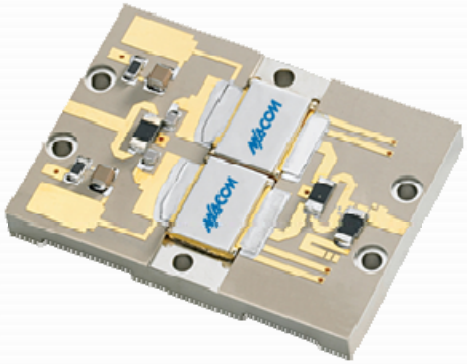
- MACOM has extensive experience in high power plastic packaging
- Demonstrated performance at 2.45GHz with GaN-Si in plastic
- Thermally enhanced high power plastic packaging
- TO272 has lower thermal resistance than legacy ceramic flanged packages

High Power Pallets and Module Capabilities

- MACOM has a well established capability for the design and manufacturing of high power pallets and modules







Industrial Heating/Cooking- Solid State Motivation

- **Multiple kW systems at 896/915/2450 MHz currently rely on high power magnetrons as microwave source**
- **High kW magnetrons have various disadvantages:**
  - Short life time of ~ 1yr running
  - High replacement costs
  - Lack of dynamic power control
  - Spectral purity and power variation
  - Very high voltages (20 kV)
- **Current GaN power amplifiers provide:**
  - > 20 yr life time
  - >70% efficiency
  - 50 V supply
  - Stability, robustness, dynamic power control and high spectral purity
- **Given advances of solid-state amplifiers, high power oven manufacturers are looking to replace existing magnetron systems**

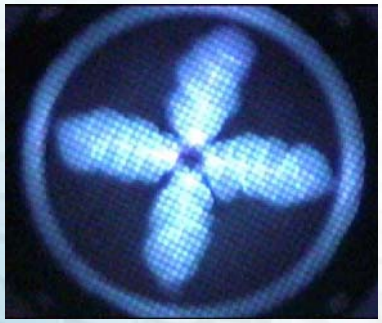
Automotive Ignition – Solid State Motivation

Concept: Add RF Energy to existing HEI ignitions to improve fuel efficiency

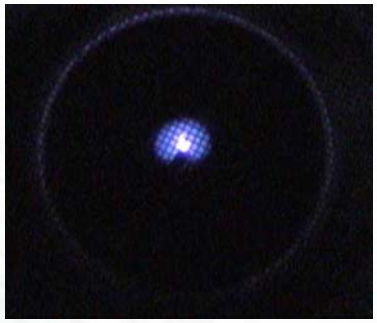
- Gain 10% or more in efficiency
- Allows car OEMs to meet 2017 CAFÉ standards
- As add on – system could fail and car would still run

Potential Market Size:

- World wide estimate of 80M cars sold
- If even 25% penetration and 2 transistors/cylinder and 4 cylinders per car on average (500W) = 160 M transistors/year!
- Roughly 4X the ENTIRE Base Station power transistor market
- Or 16X the BTS market at 100% penetration
- That does not include trucks or other non-personal automobiles!



With RF Energy



Without RF Energy

Plasma Lighting- Solid State Motivation

<u>Concept:</u> - Use RF energy to excite plasma in a light bulb to generate efficient and near ideal color temperature light

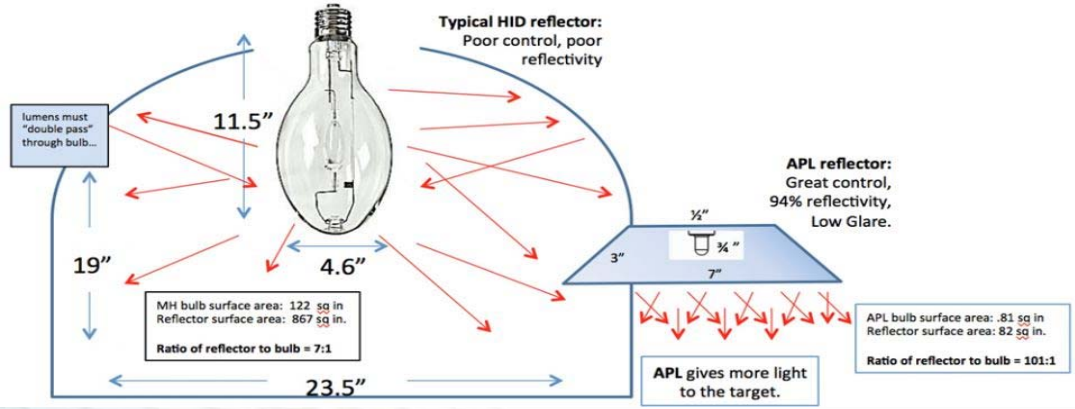
- US based (CA) start ups pioneered this technology
- Color temperature near true sunlight
- Other advantages such as dimming ability, fast re- strike, high efficiency
- Lower capital costs, lower energy costs, lower maintenance
- Only possible with Solid State transistors

<u>Potential Market Size:</u>

- LED lighting estimated at $500M in 2015, >$2B in 2020
- Global shipments of fixtures >$100B

<u>Applications:</u>

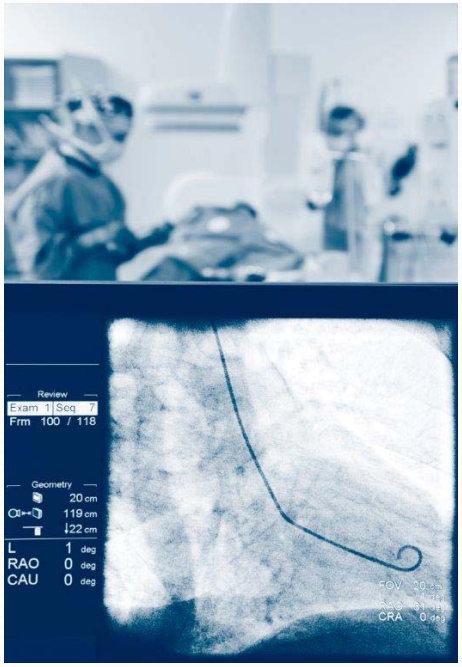
- Traditional high bay, street light
- Stadium lighting
- Grow lighting
- Accent lighting (car dealers etc)



Motivation for Medical

Concept: - Use RF energy to destroy cancer cells and other abnormal cells

- Proven treatment where other surgery is not possible
- Significantly less invasive treatment
- RF ablative heating can improve chemotherapy effectiveness
- 2.45GHz is optimal for probe (antenna) size



Potential Market Size:

- Current market size of $250M 2015
- With increasing FDA approvals and project CAGRs, >$1B in 2020

Applications:

- Cancer Treatment
- Soft Tissue Lesions
- Pain Management

MACOM Advantage:

- GaN-Si can provide up to 10% higher efficiency at 2.45GHz versus existing LDMOS solutions
- Resulting in smaller overall systems and less heat management for 300W and larger systems

Future of RF Energy- Conclusions

- **RF energy applications at the very early stages of their evolution:**
  - Magnetron replacement
  - Auto ignition
  - High bay lighting
  - Medical
  - Industrial heating/drying
- **Initial products have/will launch with LDMOS technology**
- **GaN/Si is the ultimate technology step due to:**
  - Efficiency
  - Power density
  - Cost advantages
  - High frequency/broadband capability

Uniquely Enabling RF Energy Markets

GaN-Si Process

High Power Plastic Packaging

Modules and Pallets

70% Efficient Gen 4 GaN-Si

For More Information Please Visit:

www.rfenergy.org

www.macom.com/rfenergy