



# VFM Applications

# Table of Contents

**1. Who We Are**

**2. VFM Technology**

**3. WHY VFM**

**a. Semiconductors**

**b. Secondary Battery**

**c. Automotives**

**d. Space Industry**

**e. Bio-Healthcare**

# Who We Are

## About Lambda

Founded in 1994, Lambda has become a global leader in microwave technology, specializing in Variable Frequency Microwave (VFM) systems. Collaborating with renowned institutions such as Oak Ridge National Laboratory, Lambda developed the world's first VFM technology, revolutionizing material processing. As the only company exclusively focused on VFM, we have sold over 350 systems worldwide, delivering unparalleled precision and efficiency in industries ranging from semiconductors to life sciences.

### Our Mission

At Lambda, our mission is to transform industries by providing innovative Variable Frequency Microwave (VFM) solutions that optimize efficiency, precision, and sustainability. Our technology significantly reduces processing time and energy consumption, enabling our partners to meet operational goals while contributing to environmental responsibility. By leveraging cutting-edge research and fostering global collaborations, we aim to deliver systems that not only meet but exceed industry standards, aligning with modern ESG principles.

### Our Global Reach

Over the years, Lambda has partnered with more than 100 clients worldwide, spanning industries such as semiconductors, aerospace, automotive, and healthcare. Our technology is trusted by industry leaders, including collaborations with NASA, Oak Ridge National Laboratory, and top semiconductor manufacturers. With over 350 VFM systems installed globally, we have a proven track record of delivering solutions that drive innovation and efficiency for companies of all sizes.



### Our History: Key Milestones

- 1994: Lambda Technologies founded, focusing on innovative microwave solutions.
- 1995-1997: Developed and launched the first-generation VariWave-I systems, advancing VFM technology.
- 1998: Introduced the MicroCure line of high-volume manufacturing (HVM) systems at Semicon West.
- 2002: Delivered a complete VFM solution to our first major customer, who now operates over 100 systems globally.
- 2005: Partnered with Oak Ridge National Laboratory (ORNL) to enhance VFM applications. Launched the Roll-to-Roll (R2R) system for flexible material processing.
- 2010: Delivered the 200th VFM system, marking significant global adoption.
- 2015: Expanded into aerospace and automotive industries, developing advanced VFM solutions for composite curing and bonding.
- 2020: Delivered the 350th VFM system, further expanding into healthcare and life sciences.
- 2024: Secured 33 VFM-related patents, with 17 more patents filed this year, ensuring Lambda's technological leadership.

# Variable Frequency Microwave

## Variable Frequency Microwave Technology

Lambda's Variable Frequency Microwave (VFM) technology revolutionizes material processing. By cycling through 4,096 frequencies every 25 microseconds, VFM provides unprecedented precision and control, ensuring optimal energy distribution for even the most demanding industrial applications.

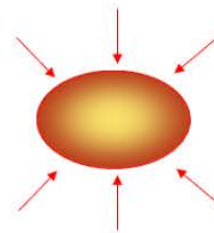
### How VFM Works

VFM leverages dielectric relaxation to generate heat at the molecular level, utilizing the rotational motion of polar molecules. This ensures:

- **Uniform Heating:** Achieves consistent temperature distribution, eliminating hot spots and improving product uniformity.
- **Volumetric Heating:** Heat is generated throughout the entire material, reducing cycle times and enhancing efficiency.
- **Selective Heating:** VFM can precisely target specific materials or components, enabling advanced multi-material processing.

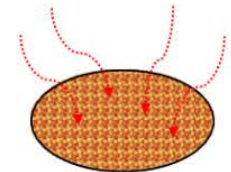
This advanced sweeping technology also prevents arcing when processing conductive materials, making it safer and more versatile than conventional systems.

### Convection Heat Outside - In

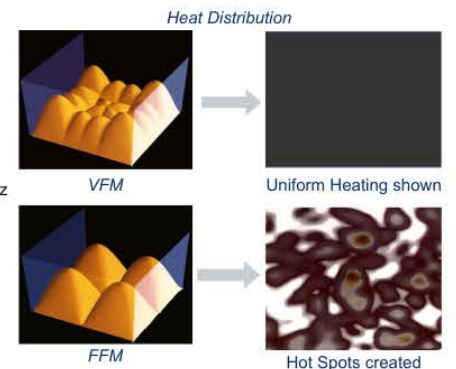
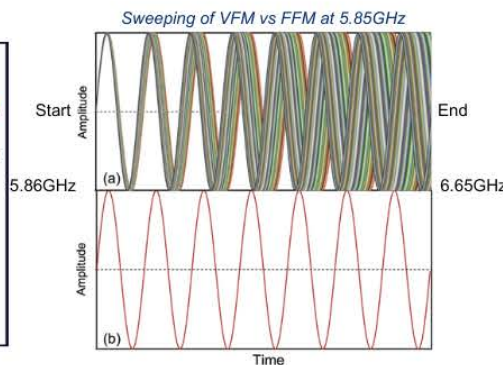
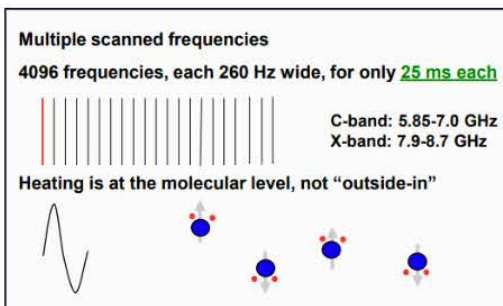


[Convection Cure]

### Microwave Heat Molecular level



[Radiation Cure]



# WHY VFM

## The Need for Innovation

In today's fast-evolving industrial landscape, traditional heating methods such as convection, infrared, and fixed-frequency microwaves often fail to meet the demands of modern material processing. Challenges such as uneven heating, high energy consumption, long cycle times, and limited material compatibility highlight the need for advanced solutions. Lambda's Variable Frequency Microwave (VFM) technology addresses these pain points with unmatched precision, efficiency, and versatility.

### Key Benefits of VFM Technology

- **Benefits of Rapid Heating**
  - **Increased Throughput Potential:** Processes are accelerated, reducing production bottlenecks.
  - **Reduction in Work-In-Process Inventory:** Faster processing allows for leaner inventory management.
  - **Reduced Thermal Budget:** VFM reduces the total energy required, making manufacturing more cost-effective.
- **Benefits of Low-Temperature Heating**
  - **Operates below critical temperature thresholds,** preserving material integrity and preventing thermal damage.
- **Benefits of Selective Heating**
  - **Reduces stress buildup** caused by mismatched thermal expansion (CTE mismatch).
  - **Enables precise targeting** of specific materials or layers for optimized design and performance.
- **Benefits of Precise Cycle Control**
  - **Offers optimized curing cycles** through step profiles, enabling precise process control and uniform results.

### Market Challenges and Key Comparisons

- **Increasing Warpage Issues (Mold Process & Underfill)**
- **Selective Anneal & Cure with Low Temperatures**
- **Achieving Good Uniformity Without Hot Spots or Thermal Runaway**
- **Managing Thermal Budgets**
- **Low Temperature and Low Power Requirements**
- **Fast and Efficient Curing Processes**
- **Residual Moisture Problems in Drying Processes**

Key Features	VFM	FFMW	IR/CONV.
Rapid and volumetric heating at a molecular level	Yes	Yes	No
Selective heating of target materials	Yes	No	No
Avoids hot spots and thermal runaway	Yes	No	Slow
Scalable for large areas with uniformity	Yes	No	Slow
Safe for use with metals and electronics	Yes	No	Yes

Process	Convection Time	VFM Time
Flip Chip	30 min - 2 hrs	2 - 10 min
Glop Top	1 - 2 hrs	5 - 10 min
Post Mold Cure	4 - 6 hrs	15 - 20 min
Wafer Coating	4 - 8 hrs	20 - 60 min
Flex Coating	4 - 8 hrs	10 - 20 min
Smart Card	6 - 12 hrs	2 - 5 min
Die Attach	1 - 2 hrs	5 - 10 min
Optical	1 - 2 hrs	10 - 15 min





# Semiconductors

## Impact on the Semiconductor Industry

Lambda's Variable Frequency Microwave (VFM) technology is transforming the semiconductor industry by addressing critical challenges in precision heating and advanced material processing. From wafer annealing to underfill curing, our systems deliver unparalleled efficiency, uniformity, and precision—ensuring optimal performance for high-demand semiconductor applications.

### Key Applications

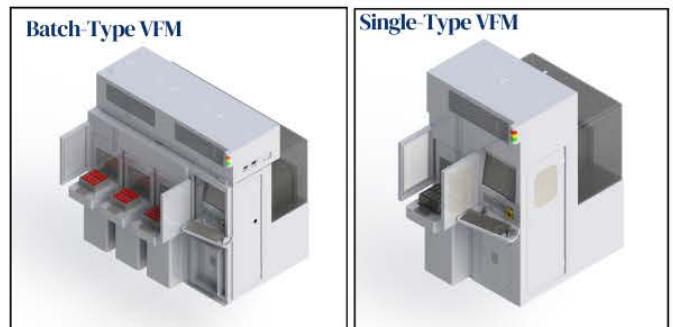
- **Wafer Annealing:** Achieves rapid and uniform heating for enhanced material properties without introducing thermal stress.
- **Underfill/Post Mold Cure:** Ensures uniform curing in advanced packaging processes like flip-chip and 3D ICs.
- **Epoxy Curing:** Provides precise and rapid curing for adhesives used in semiconductor assembly.
- **Solder Reflow:** Enables reliable connections by reducing the risk of thermal damage during soldering.

### Benefits of VFM in Semiconductors

- **Wafer Annealing:** Achieves rapid and uniform heating for enhanced material properties without introducing thermal stress.
- **Underfill Curing:** Ensures uniform curing in advanced packaging processes like flip-chip and 3D ICs.
- **Epoxy Curing:** Provides precise and rapid curing for adhesives used in semiconductor assembly.
- **Solder Reflow:** Enables reliable connections by reducing the risk of thermal damage during soldering.

### Systems for Semiconductor Applications

- **MicroCure Series:** Designed for high-volume manufacturing, these systems provide efficient curing for advanced packaging.
- **VariWave Systems:** Ideal for laboratory wafer-level applications, offering precise temperature control and uniform heating across substrates.
- **Batch-Type/Single-Type VFM Systems:** Developed for flexible electronics and continuous processing of semiconductor materials.



**LAMBDA**  
MICRO  
TECHNOLOGIES



# Secondary-Battery

## Impact on the Battery Industry

Lambda's Variable Frequency Microwave (VFM) technology has revolutionized the production of secondary batteries by optimizing critical processes such as electrode drying, binder curing, and material development. With unparalleled precision, uniform heating, and energy efficiency, VFM addresses the challenges of battery manufacturing, enabling the creation of high-performance and sustainable energy storage solutions.

### Key Applications

- **Electrode Drying:** Rapid and uniform moisture removal enhances material integrity and extends battery life.
- **Binder Curing:** VFM ensures even binder distribution across electrode layers, improving mechanical stability and reducing defects.
- **Material Development:** Supports innovation in cathode and anode materials for higher energy density and improved charge-discharge rates.

### Benefits of VFM in Batteries

- **Uniform Heating:** Eliminates thermal gradients, ensuring product consistency.
- **Faster Processing:** Reduces cycle times by up to 50%, increasing productivity.
- **Energy Efficiency:** Cuts energy use by up to 70%, supporting sustainable production.
- **Enhanced Integrity:** Preserves structural and chemical properties of sensitive materials.

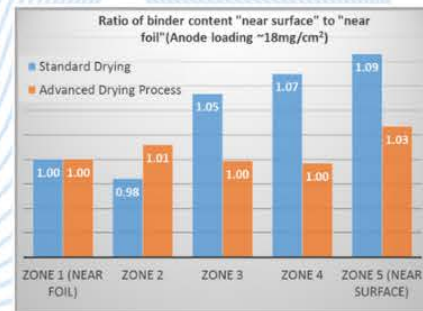
### Systems for Battery Applications

- **MicroCure Series:** Precision systems for efficient high-volume drying and curing.
- **VariWave Systems:** Flexible solutions for R&D and pilot-scale production.
- **Roll-to-Roll (R2R) Systems:** Customizable for continuous, large-scale manufacturing.

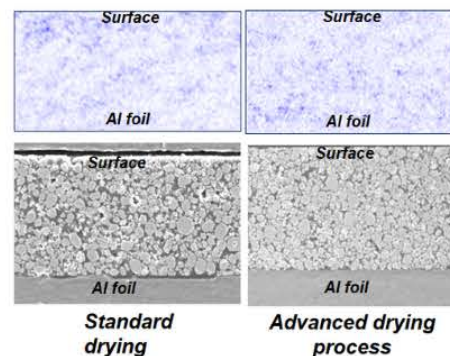


### Improved Binder Distribution with VFM

- **VFM Advantage:** Achieves uniform binder ratios from surface to foil layers, ensuring optimal electrode performance.



- Binder is located at the dark blue spots in the EDX spectra
- Binder distribution ratio (electrode surface to near foil substrate) observed values were <1.3 target





# Automotives

## Impact on the Automotives Industry

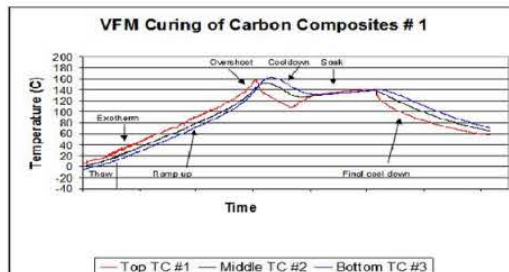
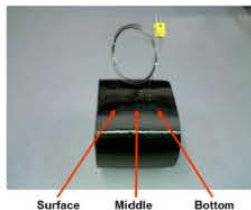
Lambda's Variable Frequency Microwave (VFM) technology provides advanced heating solutions for the automotive industry, enabling faster, more efficient, and precise processes for composite bonding, curing, and material development.

### Key Applications

- **Composite Bonding:**
  - VFM delivers precise, localized heating for bonding composite materials, reducing curing times to as low as 6 minutes (85°C), compared to 30 minutes in conventional methods.
- **Thick-Wall Composite Curing:**
  - Ensures uniform temperature distribution in thick composites, eliminating thermal stress and improving material integrity.
- **High-Performance Composite Processing:**
  - VFM cures aerospace-grade BMI resin composites faster (2 hours vs. 12 hours in autoclaves) with improved Tg (258°C) and fewer voids.

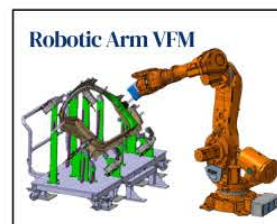
### Benefits of VFM in Automotives

- **Faster Processing:** Accelerates curing and reduces cycle times by up to 80%.
- **Precision Heating:** Localized heating ensures material integrity without affecting adjacent components.
- **Energy Savings:** Cuts energy consumption significantly, supporting sustainable manufacturing.
- *Example: Cure of resin in thick wall carbon composites.*

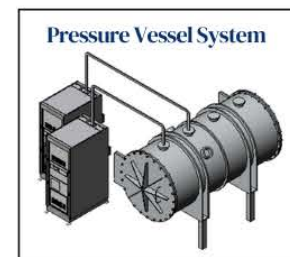
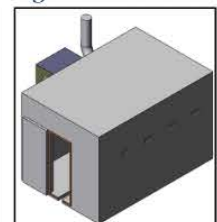


### Systems for Automotives Applications

- **Robotic Applicator Approach:**
  - Features a horn antenna to apply microwave energy precisely along a programmed path, targeting specific areas like studs or bond lines.
  - Enables efficient spot curing in under 1 minute.
  - Can be mounted on carts for repair applications.
- **Large Process Chamber Systems:**
  - Scalable solutions for large composite parts.
  - Features recipe-based VFM curing and selective heating capabilities.
- **Pressure Vessel Systems:**
  - Designed for vacuum bag parts in pressurized environments.
  - Fully integrated controls for advanced curing of larger composites.



Large Process Chamber



**LAMBDA**  
MICRO  
TECHNOLOGIES





# Space Industry

## Impact on the Space Industry

Lambda's Variable Frequency Microwave (VFM) technology is transforming space exploration by enabling efficient, cost-effective, and sustainable in-situ resource utilization (ISRU). Through advanced sintering and material processing capabilities, VFM facilitates the construction of essential infrastructure, such as landing pads, roads, and habitats, directly from local resources like lunar regolith. These innovations reduce reliance on materials transported from Earth, significantly cutting mission costs and complexity.

### Key Applications

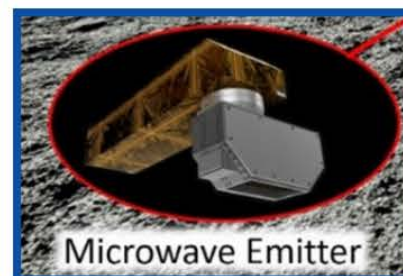
- Lunar Regolith Sintering
- VFM systems provide precise and uniform heating for sintering lunar regolith, transforming loose soil into solid, durable structures suitable for landing pads, roads, and protective habitats.
- Infrastructure Development
- Our technology enables the creation of critical infrastructure for lunar and planetary missions, such as radiation shielding, roadways, and storage facilities, supporting long-term human presence in space.
- Material Research and Development
- Lambda's VFM systems are used in the development of advanced materials for space applications, including high-performance composites and protective coatings.

### Benefits of VFM in the Space Industry

- **Energy Efficiency:** Reduces power consumption during sintering and material processing, a critical factor in off-Earth missions.
- **Material Versatility:** Processes a wide range of materials, including lunar regolith, for diverse construction needs.
- **Precision Heating:** Ensures uniform temperature control, preventing material cracking and ensuring structural stability.
- **Scalability:** Supports the construction of both small-scale structures and large habitats for lunar and planetary missions.

### Systems for Space Applications

- Lambda's custom-designed microwave emitter is engineered for use in extraterrestrial environments as part of NASA's MASON project. Attached to space exploration vehicles, this innovative system sinters lunar regolith into solid, durable surfaces in real-time, enabling the creation of roads, landing pads, and protective habitats.
- The emitter's precise energy distribution and uniform heating capabilities ensure structural integrity and adaptability to harsh lunar conditions, making it essential for constructing critical infrastructure during planetary exploration missions.



Microwave Emitter



**LAMBDA**  
MICRO  
TECHNOLOGIES



# Bio-Healthcare

## Advancing Healthcare with VFM Technology

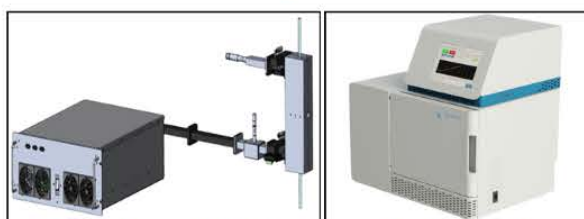
Lambda's Variable Frequency Microwave (VFM) technology is revolutionizing bio-healthcare processes by providing precise, efficient, and scalable solutions. From viral inactivation to sterilization and plasma processing, VFM addresses key challenges in the biotech and healthcare sectors, ensuring safety and consistency without compromising the integrity of sensitive materials.

### Market Challenges in Bio-Healthcare

- Inconsistent results with conventional fixed-frequency systems.
- Difficulty in scaling processes for industrial applications.
- Challenges in preserving protein functionality during sterilization.
- Need for precise thermal control to ensure safety and effectiveness.

### Systems for Bio-Healthcare Applications

- Table-Top Batch VFM
  - Power Output: 100-200W multimode.
  - Features: Full process control with camera and IR temperature monitoring, ideal for small-scale precision work.
- Waveguide Flow VFM
  - Power Output: 100W single mode, resonant.
  - Features: Continuous flow processing for industrial-scale production.



Flow through VFM

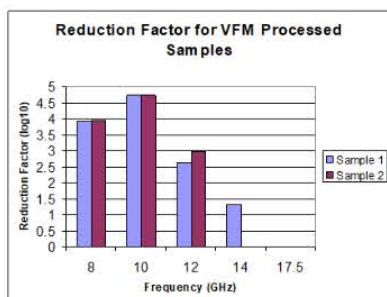
Variwave-II

### Key Applications

- Viral Inactivation and Sterilization
  - Efficiently neutralizes pathogens like parvoviruses in sealed vials.
  - Maintains up to 85% protein activity, ensuring product integrity.
- Plasma Processing
  - Offers controlled thermal environments for plasma-derived products.
  - Ensures consistency and reliability in manufacturing.
- Biotech Processes
  - Accelerates peptide synthesis, chemical digestion, and catalysis.
  - Enhances precision and repeatability in biotech research.

### Why VFM is Essential

- Flexibility in Frequency: Operates at higher frequencies with tuning capabilities to optimize energy delivery.
- Targeted Polar Molecules: Aligns with nucleic acid molecules for precise energy absorption.
- Enhanced Dielectric Losses: Reduces processing time while improving heating efficiency.
- Scalability: Adapts seamlessly from research labs to large-scale industrial production.





# Thank You



# Keep the Frequency Variable



 [microcure.com](http://microcure.com)

 [microcure@microcure.com](mailto:microcure@microcure.com)

Lambda Technologies  
2200 Gateway Centre Boulevard,  
Suite 205, Morrisville, NC 27560, USA

Lambda Micro  
#A-509, 218, Okgucheon-dong-ro,  
Siheung-si, Gyeonggi-do,  
Republic of Korea



グローバルにネットワークを広げ、最先端の科学をお客様に提供

本社：〒134-0088 東京都江戸川区西葛西6-18-14 T.I.ビル Tel. 03-3686-4711

大阪営業所：〒532-0003 大阪府大阪市淀川区宮原4-1-46 新大阪北ビル Tel. 06-6393-7411

URL : <https://www.tokyoinst.co.jp> Mail : [sales@tokyoinst.co.jp](mailto:sales@tokyoinst.co.jp)



超高真空・極低温走査型プローブ顕微鏡  
高速分光測定装置、クライオスタット



Nd:YAGレーザー、Ti:Sレーザー  
OPOレーザー