TechNote

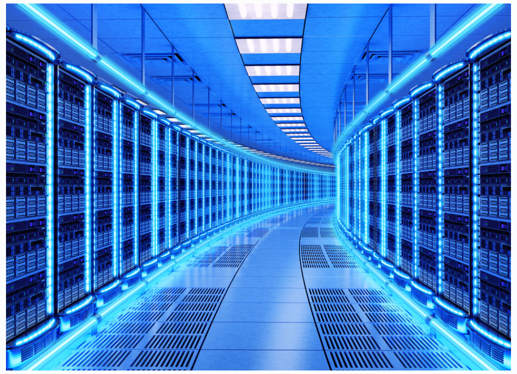
Quantum Cool™ Nanocomposite Technology

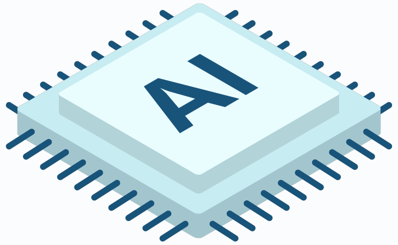
Revolutionizing Heat Exchange and Electromagnetic Wave Absorption for the Next Era

R&D M-Laboratory, H&J Industries

Rapidly Growing Needs for High-Efficiency Thermal and EMI Solutions

- AI Data Centers: Massive power demand & heat generation (projected 160% power demand increase by 2030; AI adds 200 TWh annually).
- GPU/MPU Heat Dissipation: Escalating power densities require superior heat sinks.
- LED Heat Sinks: Miniaturization drives higher thermal flux.
- Base Stations: 5G/6G evolution increases heat & EMI challenges.
- Autonomous Vehicles: EMI shielding crucial for safety-critical electronics.
- Defense/Space: EMI/heat countermeasures for satellites, high-altitude nuclear events, solar storms (particularly relevant to Japan & Taiwan).
- Recent US News: Gigantic AI data center projects (multi-GW scale) raising electricity supply concerns.



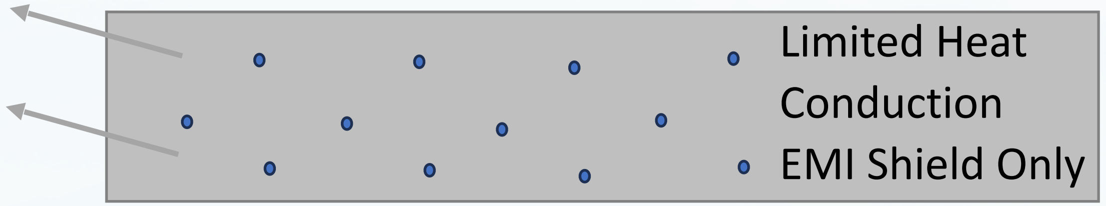


Beyond CNT Shields: Hybrid Nanocomposites

Revolutionizing Thermal Management and Electromagnetic Wave Absorption

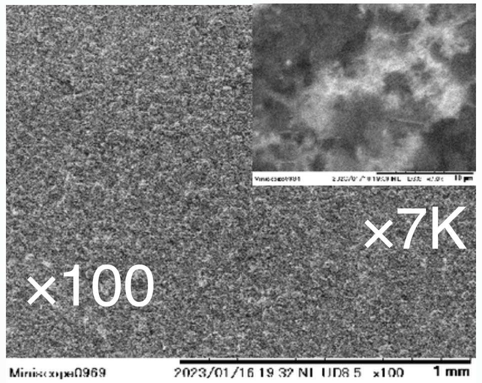
Conventional Technology

- CNT dispersed into polymer matrix to create EMI shielding material.
- Focus only on electromagnetic wave blocking (shielding).
- Limited thermal conductivity improvement.



Our Hybrid Nanocomposite Technology

- CNT/Graphene uniformly dispersed with patented method.
- Nano-Ag loading + proprietary electroplating.
- Ultrasonic & CMCA-based aqueous processing for easy coating/spraying.
- Achieves simultaneous high thermal conductivity and EMI absorption (hybrid functionality).



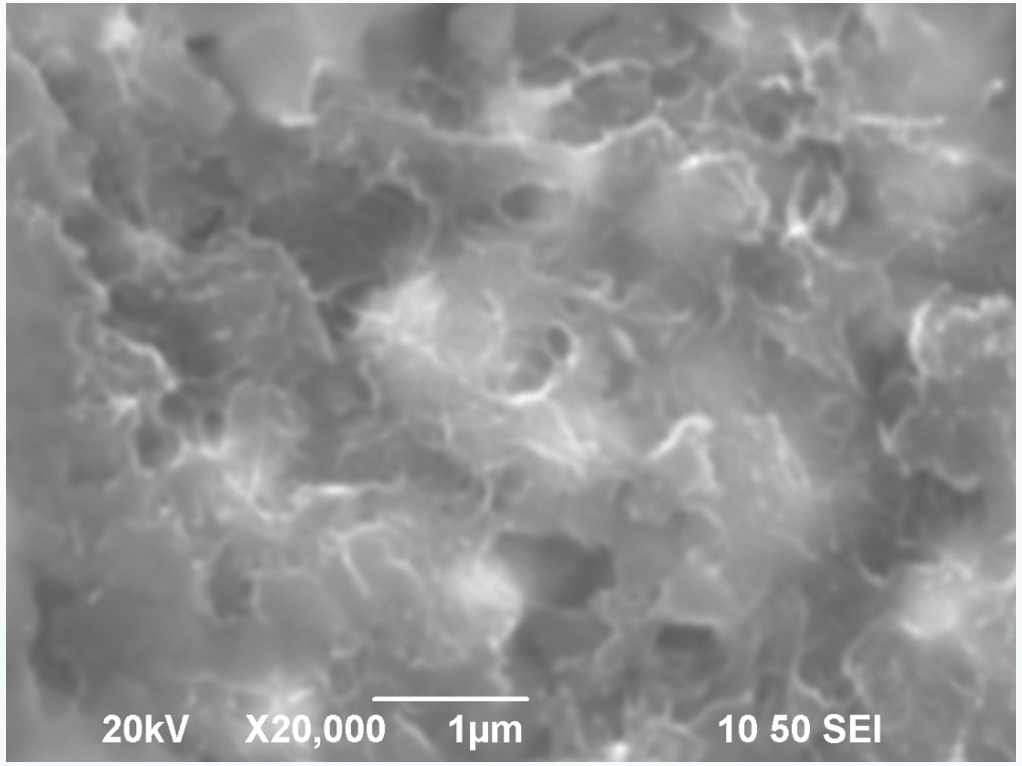
SEM image of the heat sink surface with CNT/Graphene composite electroplated with special interface treatment.

Optimized Composite Materials for Superior Thermal Conductivity

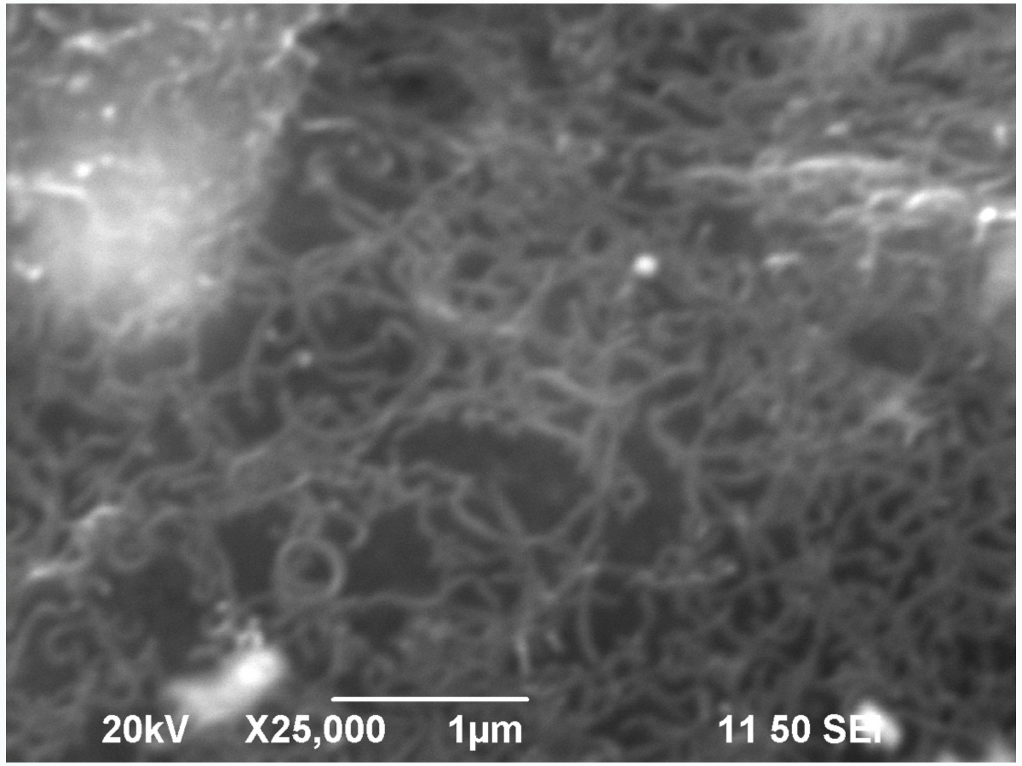
Ag/CNT composite materials are known to have higher thermal conductivity compared to single-phase Ag. This is due to the significant contribution of phonon conduction through the percolation network of CNTs. Furthermore, the optimization of composite material blending with CNT, Graphene, and Ag, combined with ultrasonic dispersion technology and proprietary electroplating techniques, achieves overwhelming thermal conductivity characteristics

Hybrid functionality: High thermal conductivity and EMI absorption in one material.

Visualizing the Technology



This is an SEM image of a high-performance heat exchange device, referred to as the Quantum Cool Device, created using a proprietary electrodeposition technology to produce a CNT/Graphene/Ag nanocomposite.



This is an SEM image of a high-performance electromagnetic wave absorber created using CNT/Graphene/Ag nanomaterials combined with CMCA.

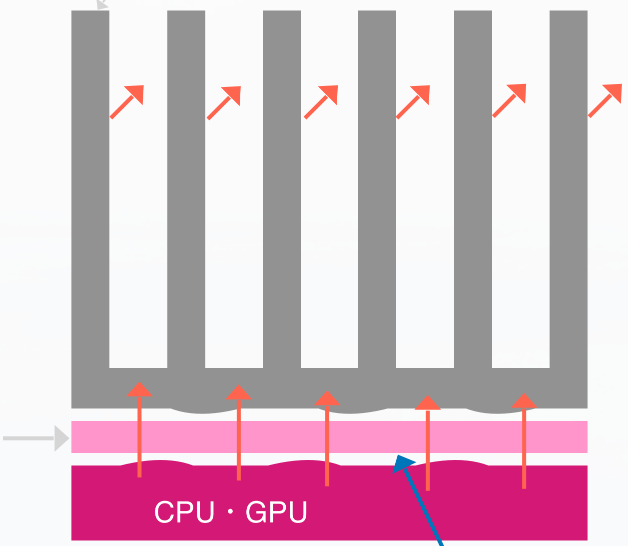
SEM Imagery

SEM images reveal the uniform distribution of CNT/Graphene/Ag nanocomposites. This structure significantly enhances thermal radiation and conductivity characteristics.

Hybrid Structure

The hybrid structure of CNTs and graphene optimizes heat transfer. Silver nanoparticles further enhance heat dissipation capabilities.

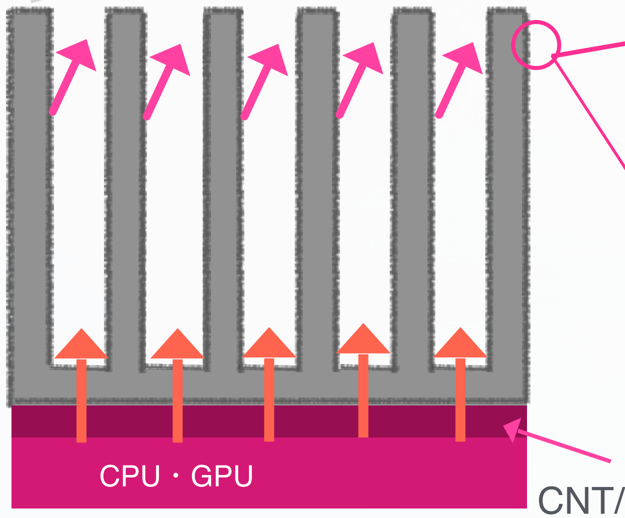
Heat Sink (Aluminum)



.VS.

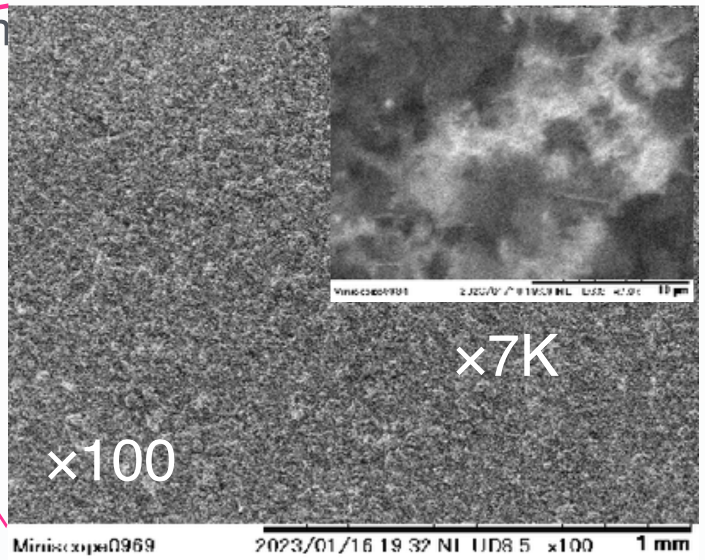
High-efficiency TIM

Quantum Cool Super Heat Sink Aluminum Substrate

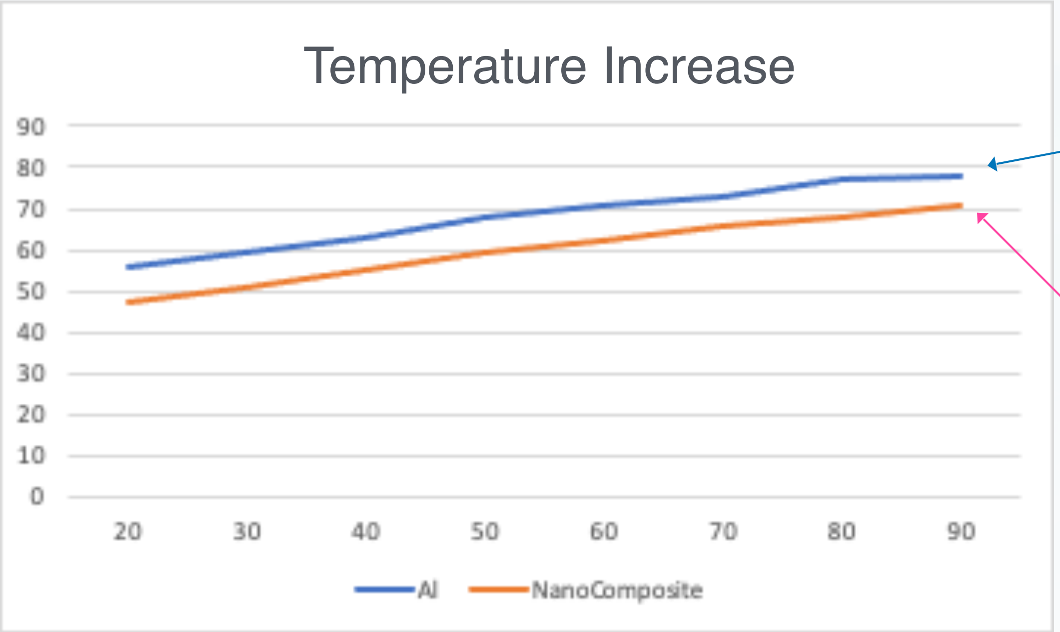


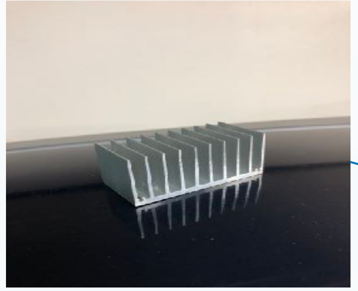
air & gap: Air & gaps due to interface irregularities

Detailed view of CNT/Graphene composite form

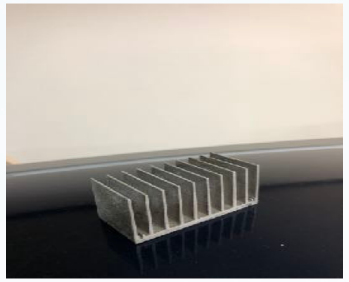


CNT/Graphene composite specially synthesized TIM

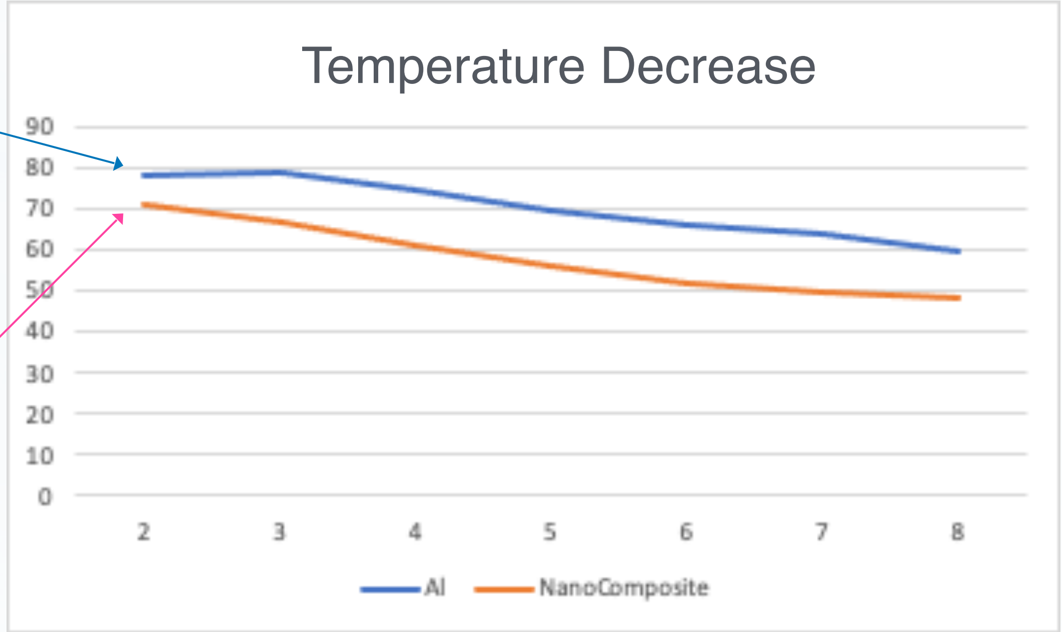




Conventional Aluminum Heat Sink



CNT/Graphene Super Heat Sink

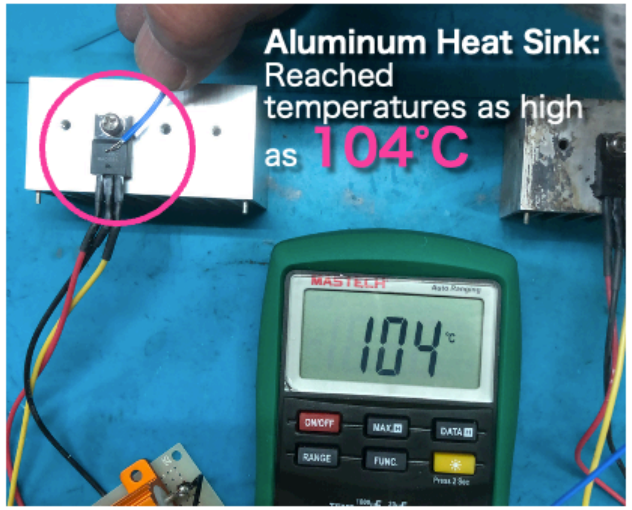


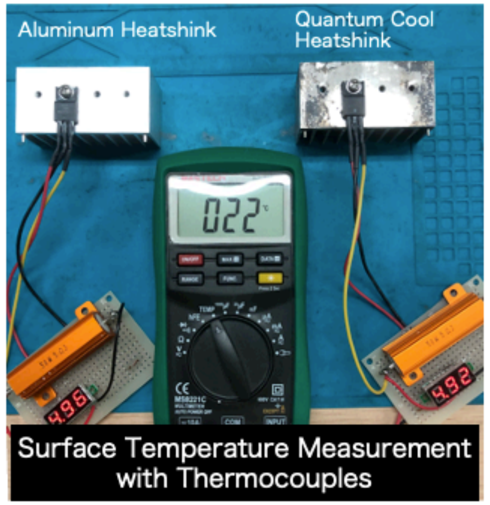
This simple example compares a small heat sink for air cooling: an aluminum alloy heat sink (Blue) and a super heat sink (Red) using a comparative experiment (thermal control plate: IKA C-MAG HS7). The experiment compares only the heat sinks themselves, and it is expected that further performance improvement can be achieved by using our proprietary TIM in combination.

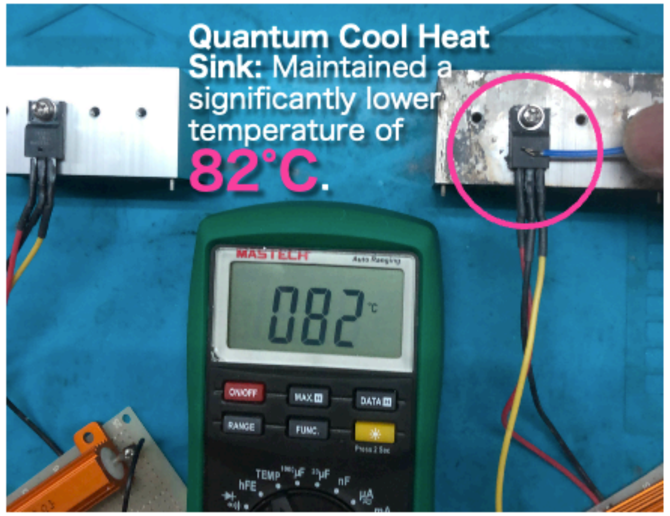
Quantum Cooling™ Device

Demonstration Experiment Using Quantum Cool Heat Sink Technology

Cooling a Three-Terminal Regulator







The innovative Quantum Cool heat sink technology substantially reduces thermal resistance

Specifications of the NJM7805 Regulator

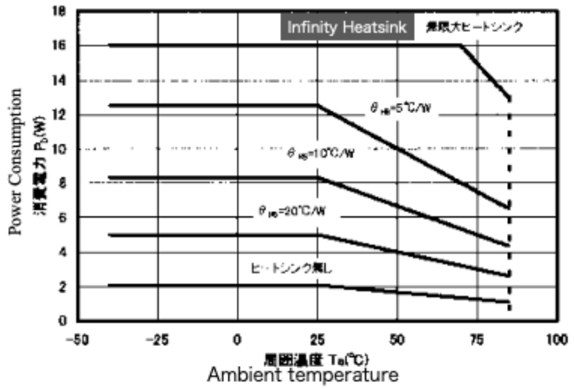
■ 電気的特性 (C_I = 0.33μF, C_O = 0.1μF, Tj = 25°C) Electrical Characteristics

測定はパルス試験とする

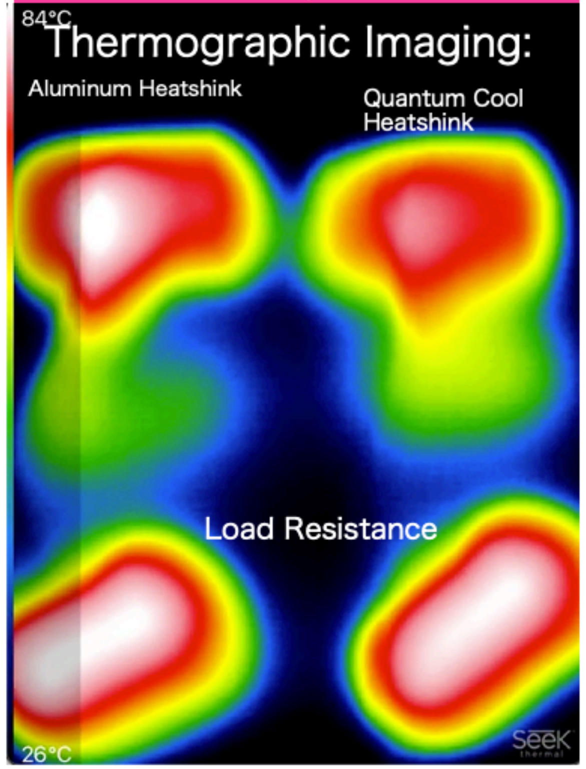
項目	記号	条件	TO-220F 最小	TO-220F 標準	TO-220F 最大	TO-252 最小	TO-252 標準	TO-252 最大	単位
NJM7805FA/DL1A									
出力電圧	V_O	V_{IN}=10V, I_O=0.5A	4.8	5.0	5.2	4.8	5.0	5.2	V
ラインレギュレーション	$\Delta V_O - V_{IN}$	V_{IN}=7~25V, I_O=0.5A	-	3	50	-	3	100	mV
ロードレギュレーション	$\Delta V_O - I_O$	V_{IN}=10V, I_O=0.005~1.5A	-	15	50	-	15	100	mV
無効電流	I_Q	V_{IN}=10V, I_O=0mA	-	4.2	6.0	-	4.2	6.0	mA
出力電圧温度係数	$\Delta V_O/\Delta T$	V_{IN}=10V, I_O=5mA	-	-0.5	-	-	-0.5	-	mV/°C
リップル除去比	RR	V_{IN}=10V, I_O=0.5A, e_{in}=2V_{P-P}, f=120Hz	68	78	-	68	78	-	dB
出力雑音電圧	V_{NO}	V_{IN}=10V, BW=10Hz~100kHz, I_O=0.5A	-	45	-	-	45	-	μV

Power Consumption Characteristics (example provided in supplementary materials)

NJM7800FA消費電力特性例
(Topr=−40~+85°C, Tj=~+150°C, P_D=16W(Tc≦70°C))



Recorded surface temperature distribution.



This experiment utilized a well-known three-terminal regulator, the **NJM7805**. These regulators typically operate by converting part of the input voltage into heat while stabilizing the output voltage, using a linear circuitry method (also referred to as a step-down regulator). Consequently, dissipating heat generated by the power transistor's voltage differential between its input and output terminals is essential. Heat sinks are a necessity in most applications.

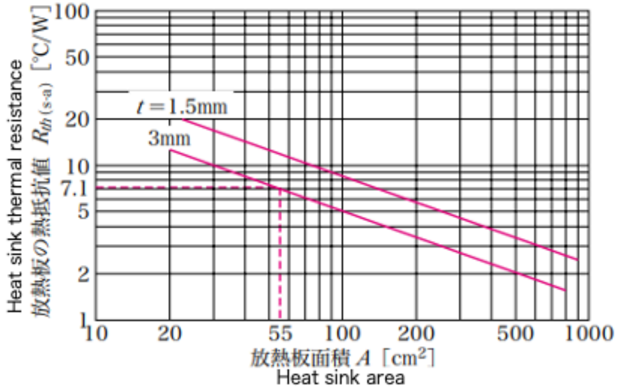
Design Considerations: The relationship between power loss and the surface area of the heat sink is critical. For instance, the following equation illustrates the relationship between junction temperature (Tj) and the heat sink's thermal resistance (Rth(s-a)):

$$R_{th(s-a)} = \frac{T_J - T_A}{P_D} - R_{th(j-c)} - R_{th(c-s)}$$

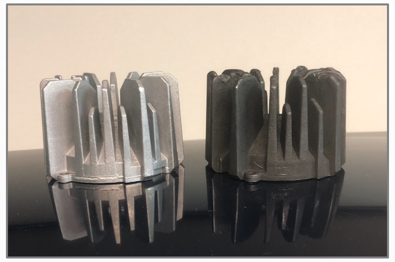
Experimental Example:

- For a load resistance conducting **0.6A**, the regulator dissipates **3.6W** of heat.
- For **1A**, **7W** of heat must be dissipated.

This requires aluminum heat sinks with thermal resistances ranging from **7.1°C/W to 2.6°C/W**, corresponding to considerable surface areas. The results demonstrate that the new **Quantum Cool** heat sink technology achieves significant thermal resistance reduction, effectively replicating an expansion of the flat surface area of aluminum heat sinks



Relationship Between Aluminum Plate Surface Area and Thermal Resistance



Super Heat Sink: CNT/Graphene/ Nano-Ag Composite

- High-Efficiency Heat Exchange Device
- Superior Thermal Conductivity: CNT/ Graphene percolation + nano-Ag synergy.
- Electroplated Thin Films on Aluminum: Enhanced mechanical strength & adhesion.
- Optimization: Phonon conduction network outperforms single-phase Ag.
- Applications: Air-cooled & liquid-cooled systems (AHU, CDU, DLC).

Technical Details: Thermal Interface and Integration

- High-Performance TIM: CNT/Graphene composite reduces thermal resistance between CPU/GPU & heat sink.
- Enhanced Contact Surface: Special electroplating interface minimizes air gaps.
- Cooling Efficiency: >10 ～20 °C improvement demonstrated in comparative experiments.
- Scalable Production: Compatible with spray or coating for large surfaces.

Electromagnetic Wave Absorption Properties

Absorption vs Reflection

Our material absorbs electromagnetic waves rather than reflecting them. This reduces overall system noise and interference.

Balanced Performance

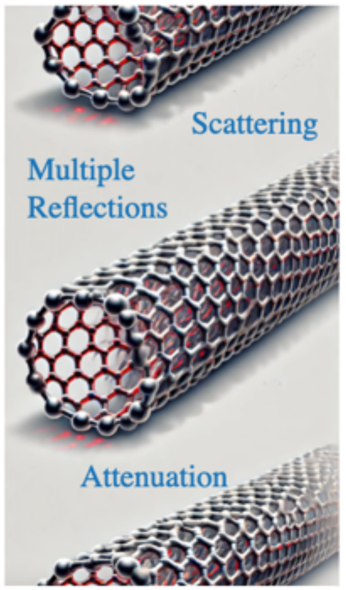
The conductivity and porous structure of CNT/Graphene/Ag allow for balanced reflection and absorption.

Customizable Characteristics

Our technology enables custom design of enhanced electromagnetic wave absorption frequency characteristics.

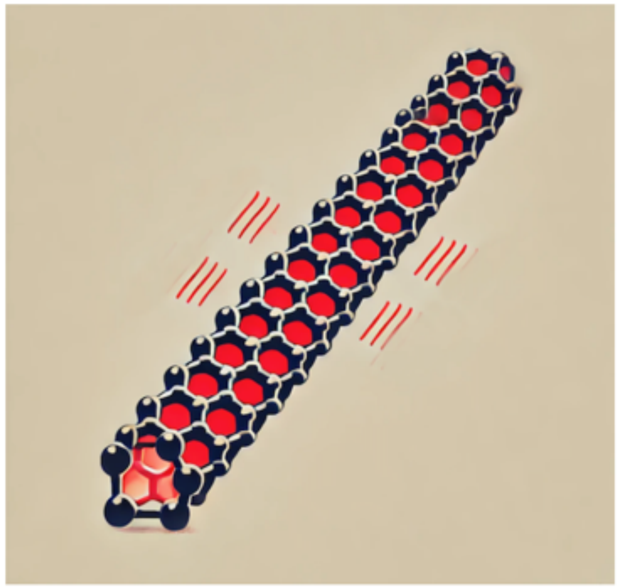
reflection, scattering, attenuation

多重反射 散乱 減衰



re-radiation prevention confinement effects

再放射防止閉じ込め効果



CNT Structure and Electromagnetic Wave Absorption

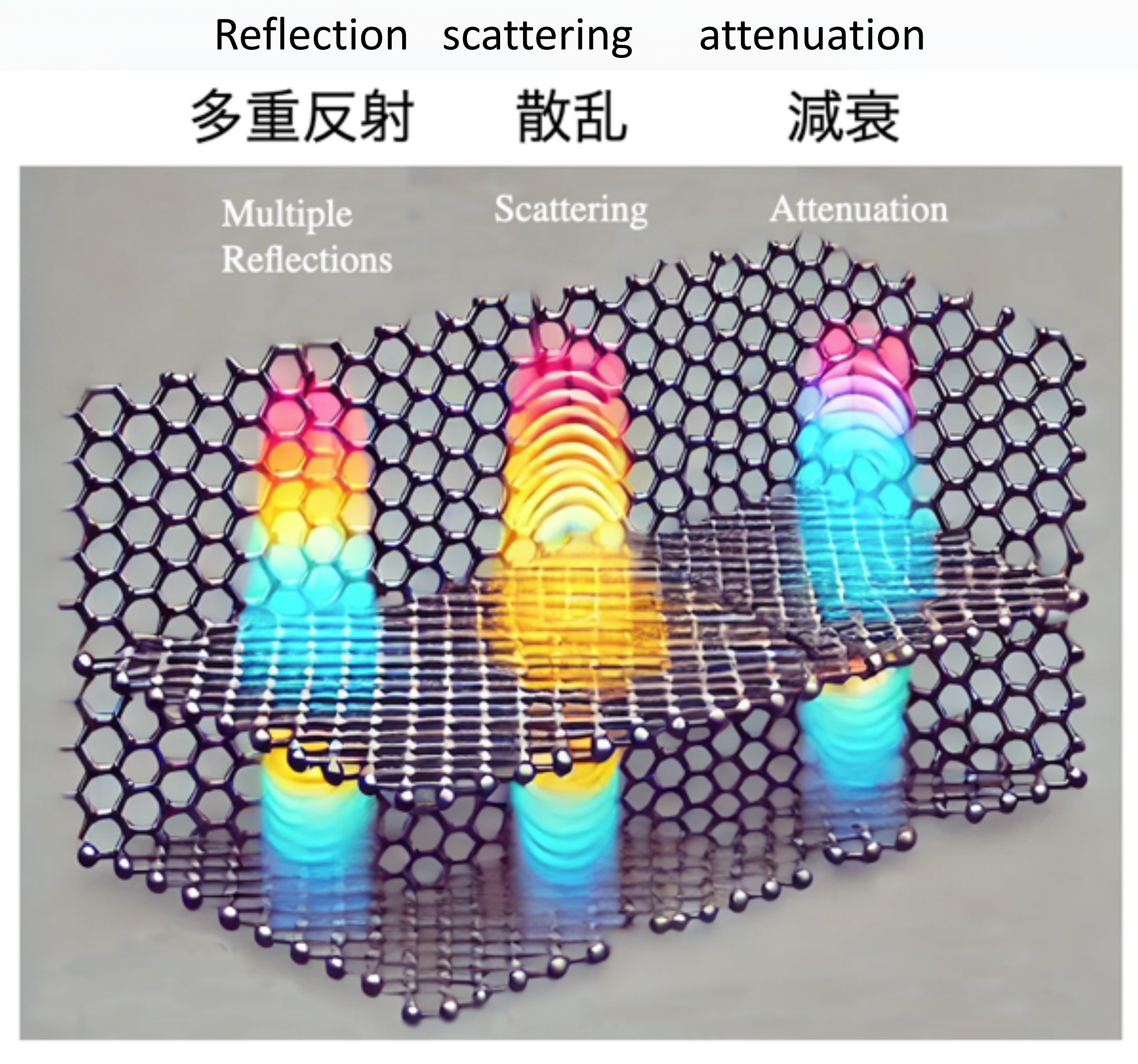
CNT Structure

CNTs are cylindrical carbon structures. Their nanometer-sized tubes interact with electromagnetic waves over a large surface area.

Wave Absorption Process

Electromagnetic waves scatter and reflect within CNTs. Energy gradually converts to heat, preventing external wave escape.

Graphene's Role in Electromagnetic Absorption



1

Graphene Structure

Single-atom layer of carbon in hexagonal lattice. High conductivity and surface area.

2

Wave Interaction

Electromagnetic waves absorbed on graphene surface. Energy converted to electric current.

3

Multi-layer Effect

Graphene plates trap waves between layers, enhancing energy dissipation.

Unique Structural Features

Synergistic Effect

CNT, graphene, and Ag nanoparticles interact to form a high-performance composite.

3D Porous Structure

Enables tunable characteristics and robust environmental performance.

Hierarchical Structure

Nano and meso-scale features combine, enhancing absorption and heat dissipation.

Design Flexibility

Nano-material composition and structure can be tailored to achieve desired attenuation characteristics at specific frequencies.

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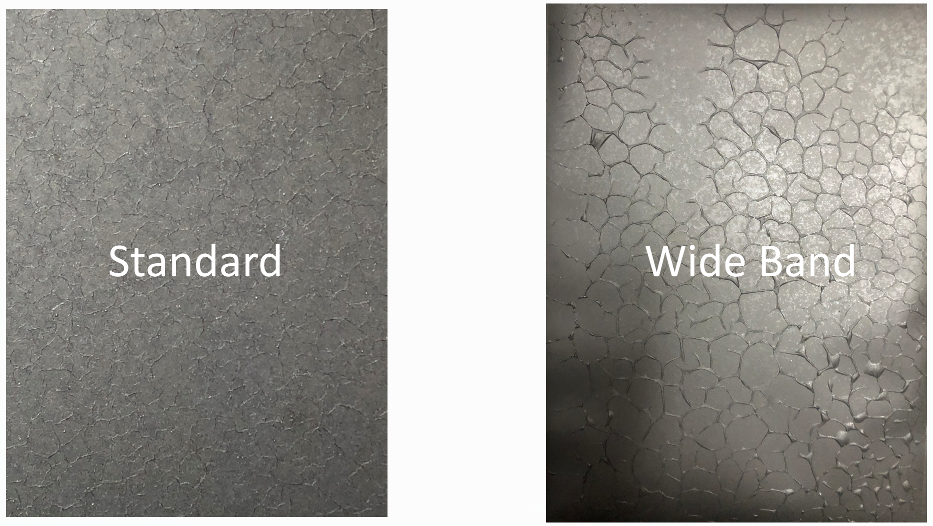
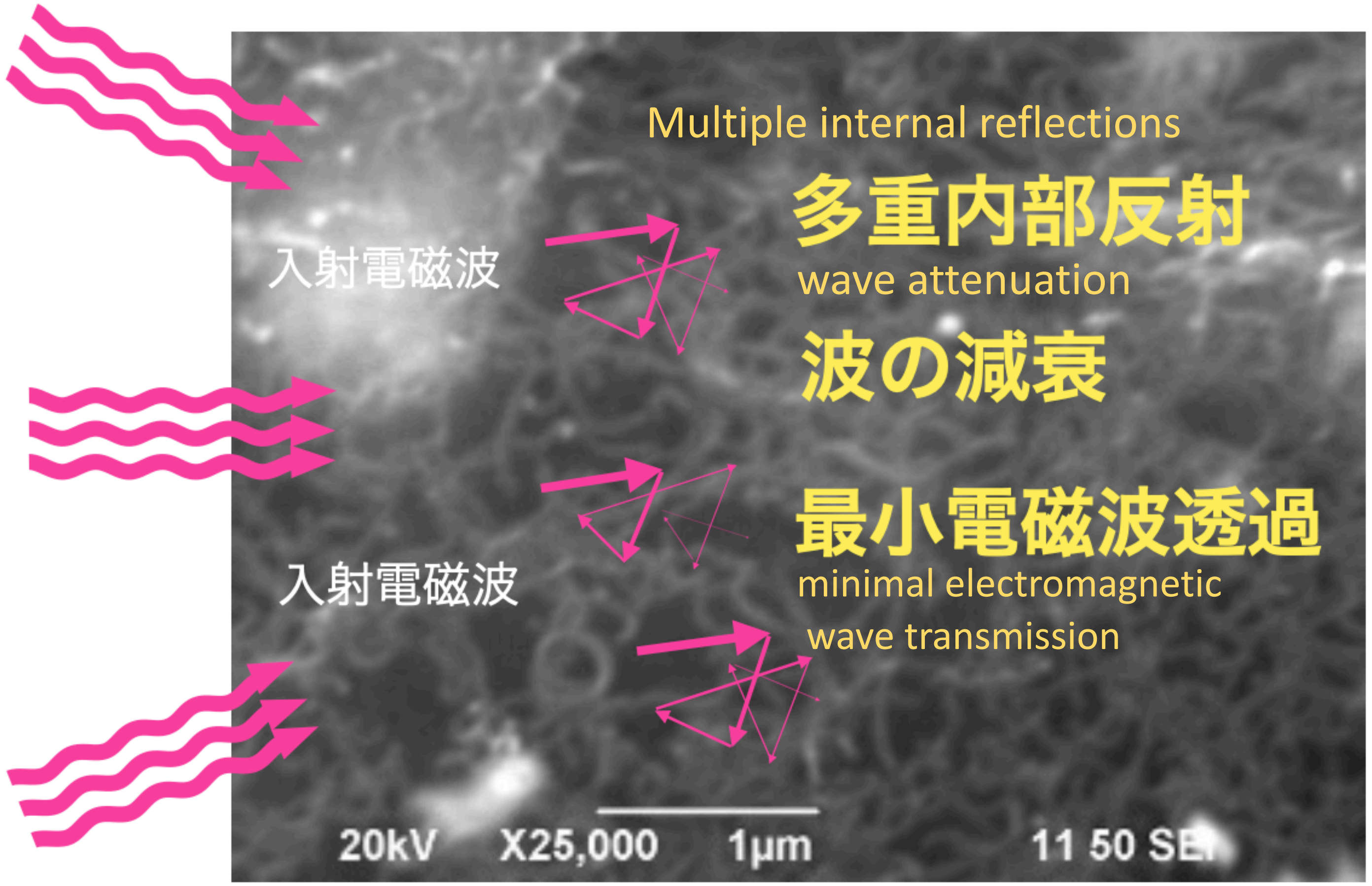


Broadband electromagnetic wave absorbing material samples



Applications and Future Prospects

1. **Aerospace**

   Lightweight, robust performance for space and aviation.

2. **Electronics**

   EMI shielding in consumer and industrial devices.

3. **Energy**

   Heat management in power systems.

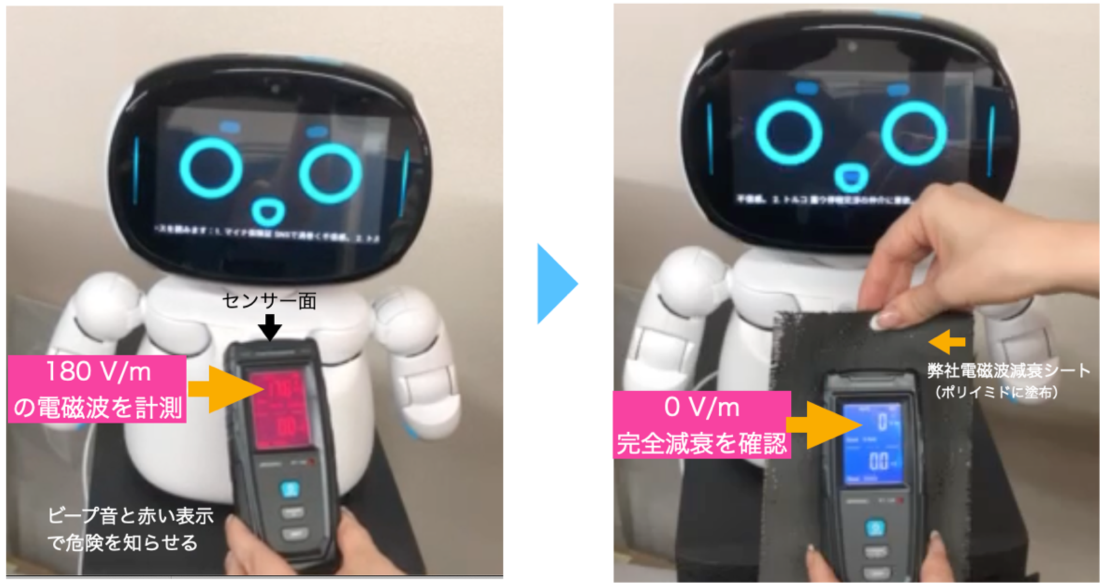
4. **Emerging Technologies**

   Adaptable to various markets and applications.

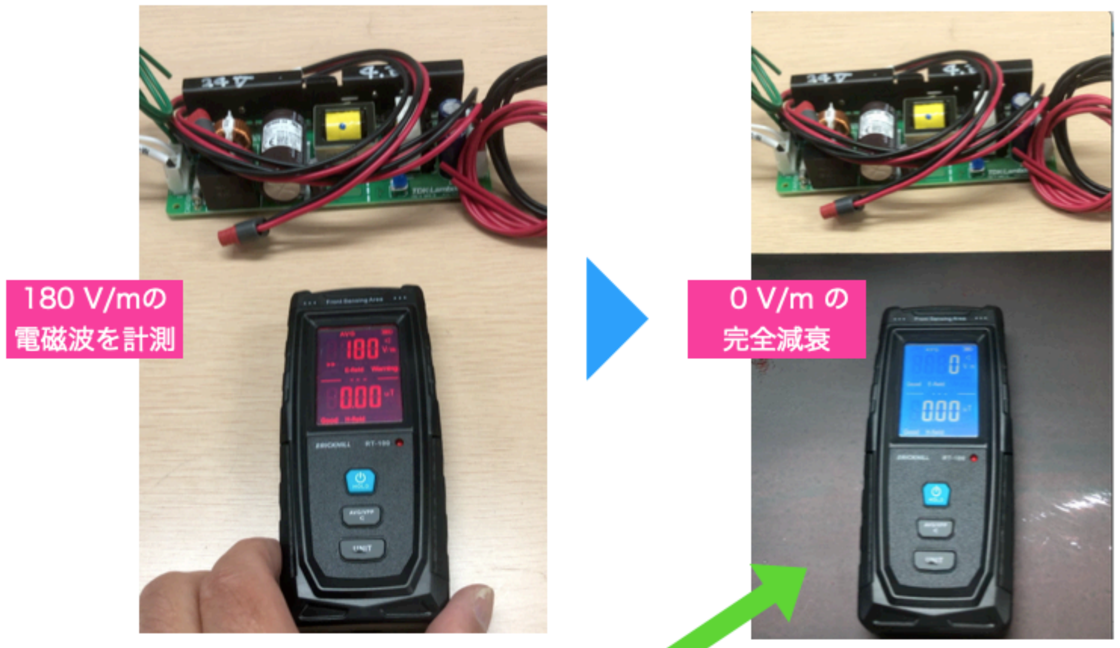
Electromagnetic Wave Attenuation Demonstration

Experiments demonstrate effective absorption of electromagnetic waves from AC-DC converters. The material significantly reduces wave intensity, showcasing its practical applications.

Completely attenuates electromagnetic waves generated from within the robot‘s body.
Robot 胴体内部からの発生する電磁波を完全に減衰させる



Electromagnetic Wave Absorption Experiment from an AC-DC Converter



電磁波減衰シートに載せるだけで完全減衰を実現
Achieves complete attenuation simply by placing it on the electromagnetic wave attenuation sheet