**Supplementarily Materials B: More information**

**Theoretical insights manifested by wave mechanics theory of microwave absorption— Part 2: A perspective based on the responses from DeepSeek**

Yue Liu1, \*, Michael G. B. Drew2, Ying Liu1

1College of Chemistry and Chemical Engineering, Shenyang Normal University, Shenyang, P. R. China,110034, yingliusd@163.com (Ying Liu), yueliusd@163.com (Yue Liu)

2School of Chemistry, The University of Reading, Whiteknights, Reading RG6 6AD, UK, m.g.b.drew@reading.ac.uk

\* Corresponding author

**Supplementary material IB**

**Question to DeepSeek**

Under what circumstances is microwave absorption only related to the interface of the material and not to the properties of the material itself?

**Response from DeepSeek, Version 2 (English translation from Chinese)**

In the microwave absorption process, the electromagnetic characteristics of the material itself (such as dielectric constant and permeability) usually play a leading role. However, under the following special cases, microwave absorption may be primarily related to the interface structure of the material, but not to the inherent properties of the material itself:

1. **Ultrathin materials or metasurface design**

When the thickness of the material is much smaller than the microwave wavelength (such as sub-wavelength thickness or metasurface structure), the interaction between electromagnetic waves and materials mainly occurs near the interface at this time:

**Structure-led absorption**: By designing periodic subwavelength structures on the interface (such as metal resonant rings, nanoantenna arrays), the reflection, transmission and local field enhancement effects of electromagnetic waves can be controlled to achieve selective absorption.

**Material properties take the secondary**: If the loss of the material itself is extremely low (such as low-loss medium), absorption is mainly determined by the electromagnetic resonance of the interface structure (such as surface plasmon resonance, magnetic resonance), rather than the dielectric or magnetic loss inside the material.

**Example:**

The metasurface absorber stimulates local electromagnetic resonance through the periodic structure of metal-dielectric, and the absorption peak is determined by structural parameters (such as unit size, period) and the intrinsic loss of the material.

1. **Multilayer Interference Structure**

In multilayer materials, microwave absorption of base destructive interference can be achieved by precisely controlling the thickness of each layer and the interface reflective phase:

* **Interference-dominated absorption:** microwaves reflect multiple times between multi-layer interfaces, and the reflected waves cancel each other out through phase matching, and the transmitted waves are confined in the structure, and energy is dissipated through the interference effect.
* **Material loss is not necessary:** ​​Even if the material itself has low loss (such as low-loss dielectric film), efficient absorption can still be achieved as long as the thickness and interface reflection of the multi-layer structure meet the interference conditions.

**Example:**

In the Fabry-Pérot Resonance cavity, a dielectric layer of a specific thickness causes the incident microwave to form standing waves in the cavity, and absorbs through interference. At this time, the absorption peak is determined by the cavity thickness rather than the dielectric loss.

**3. Coherent Perfect Absorption (CPA)**

When two coherent microwaves are incident on the material interface at specific angles and phases:

* **Interference completely dissipates energy:** the reflective and transmitting components of the two beams are completely canceled by coherent superposition, and the energy is all "absorbed" by the interface even if the material itself is lossless.
* **Relying on incident wave regulation:** The absorption effect is determined by the phase, amplitude and incident angle of the incident wave, rather than the electromagnetic parameters of the material.

**Example:**

In a lossless dielectric plate, by regulating the phase difference between the two coherent microwaves, 100% absorption can be achieved at a specific frequency. At this time, the absorption mechanism completely relies on wave interference at the interface.

**4.Perfect impedance matching interface**

If the interface structure is designed to be perfect impedance matching (such as gradient refractive index layer):

**No reflection condition:** microwaves completely enter the material, and reflection is zero, and absorption is only determined by the loss inside the material.

**But if the material loss approaches zero,** the microwave will theoretically be completely transmitted and there is no absorption.

**Exception:** If the microwave propagation path is extended through the interface structure (such as gradient multilayer), even if the material has no loss, absorption can be achieved through geometric dissipation of multiple reflection paths (such as labyrinth structure), but this mechanism still depends on the structural design rather than the material itself.

**Key Conclusions**

In the following cases, microwave absorption mainly depends on the interface effect:

**1. Metasurface or subwavelength structure:** absorption is enhanced through the local field of electromagnetic resonance.

**2. ​​Multi-layer interference design:** destructive interference suppresses reflection and extends energy residence time.

**3. Coherent perfect absorption:** The coherent regulation of incident waves achieves complete energy dissipation.

In these cases, the electromagnetic parameters of the material itself (such as ε, μ) may take a secondary position, and the absorption effect is dominated by the interface structure or wavefield regulation. However, in practical applications, material properties may still indirectly affect the feasibility of interface design (such as the influence of metal conductivity on metasurface resonance frequency), but theoretically there are extreme scenarios where interface effects completely dominate.

**Supplementary material IIB**

We have checked with the same question and obtained similar responses from DeepSeek except some new information such as: “如果材料被设计成具有多层结构，每一层的界面都经过优化，使得每层之间的多次反射和干涉导致整体吸收，而每一层材料本身的损耗可以忽略，这种情况下吸收可能主要由界面间的干涉效应决定，而不是材料本身的损耗特性。… 另一个角度是，当材料的结构设计使得微波在界面处被完全吸收，而无法进入材料内部，例如使用完美的匹配层（PML），这种情况下，无论材料内部是什么，只要匹配层设计得当，吸收就由界面层决定。不过PML通常需要特定的材料参数来实现，这可能与材料本身有关，但如果是通过结构设计实现的，比如多层结构，可能可以独立于基底材料” which wrongly stated that perfect absorption at impedance matching, the incident microwaves did not penetrate and absorption took place at interface.

The responses from ChatGPT were similar.

**Supplementary material IIIB**

Question to ChatGPT：

Under what circumstances is microwave absorption only related to the interface of the material and not to the properties of the material itself?

Responses from ChatGPT:

Reasoned for 8 seconds

Microwave absorption can be dominated by interfacial effects rather than the intrinsic properties of the material when the following conditions apply:

1. **Heterogeneous or Composite Structures:**  
   When a material is made up of two or more phases with markedly different dielectric constants or conductivities, significant interfacial polarization (often referred to as Maxwell–Wagner polarization) can occur. In these cases, the charge accumulation at the interfaces greatly enhances microwave absorption, even if the bulk phases themselves have low intrinsic loss.
2. **Core–Shell or Layered Architectures:**  
   In systems where one material is coated by another (or where layers of different materials are stacked), the interface between the core and the shell (or the layers) can create a strong polarization effect. This effect can dominate the microwave absorption process if the intrinsic losses in either component are minimal.
3. **Nanostructured or Porous Materials:**  
   Materials engineered to have a high density of interfaces (for example, porous structures or nanocomposites) will have absorption largely controlled by these interfaces. Even when the individual components have weak absorption characteristics, the cumulative effect of the numerous interfaces can lead to significant microwave absorption.
4. **Low Intrinsic Loss of Constituent Phases:**  
   When the bulk dielectric or magnetic losses of the constituent materials are low, any interface that creates localized charges or field enhancements can become the primary site for energy dissipation. Thus, the overall absorption behavior reflects primarily the interfacial characteristics.

In summary, if the material’s design or structure leads to an abundance of interfaces with strong contrast in properties—and if the inherent losses of the individual phases are relatively weak—then microwave absorption will be controlled mainly by interfacial effects rather than by the intrinsic properties of the materials themselves.

**Supplementary material IVB**

Responses from Perplexity at https://www.perplexity.ai/

**Why current microwave absorption theories are wrong**

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Current theories of microwave absorption contain fundamental flaws that have led to widespread misconceptions in both industrial applications and scientific understanding. These errors stem from conceptual confusion, mathematical mistakes, and oversimplified models that fail to accurately describe the physical mechanisms at work.

Fundamental Confusion Between Films and Materials

The Core Problem

One of the most significant issues in current microwave absorption theory is the confusion between "films" and "materials"[1](https://www.qeios.com/read/QQ1MFF)[2](https://www.qeios.com/read/ZKKEZF). This confusion has resulted in the misapplication of reflection loss (RL) parameters, which should characterize metal-backed films, to describe the absorption properties of materials themselves[1](https://www.qeios.com/read/QQ1MFF)[3](https://arxiv.org/ftp/arxiv/papers/1406/1406.1847.pdf).

Films are devices composed of materials with two parallel interfaces and specific thickness, while materials are substances with intrinsic properties like permittivity and permeability[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). The distinction is crucial because films exhibit unique behavior due to back-and-forth reflections between their interfaces, creating multiple reflected beams that don't exist in uniform materials[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Misuse of Reflection Loss Parameters

Reflection loss RL is a parameter specific to devices, not materials[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). Using RL to characterize material absorption properties has led to the erroneous belief that absorption peaks in layered materials originate from the material itself or its resonances[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). In reality, these peaks result from wave interference effects specific to the film geometry.

Major Flaws in Impedance Matching Theory

Lack of Theoretical Foundation

Impedance matching theory (IM), despite being widely used to predict absorption behavior, lacks comprehensive theoretical support[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). Recent statements acknowledge that "the relationship between impedance matching and material parameters has not been accurately described so far"[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). This theory incorrectly assumes that optimal absorption occurs when the input impedance of the film equals the characteristic impedance of free space (|Zin| = |Z0|)[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Mathematical and Experimental Inconsistencies

Experimental data consistently contradicts IM predictions[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). For example, studies of Ni₀.₆Zn₀.₄Fe₂O₄ films showed that while |Zin| was much closer to |Z0| compared to composite materials, the relative values of |RL| were completely different from IM predictions[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). This contradiction persisted across the entire frequency range from 0.5-18 GHz, yet the data was still claimed to support IM[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

The theory also suffers from fundamental mathematical errors:

* It treats complex impedances as real numbers[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf)
* It ignores the effect of |Zin + Z0| in RL expressions[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf)
* It cannot explain why absorption peaks don't occur exactly at |Zin| = |Z0|[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf)

Problems with Quarter-Wavelength Theory

Absence of Rigorous Proof

Quarter-wavelength theory (QWM) also lacks strict theoretical proof based on transmission-line theory[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). Recent research acknowledges that "strict proof regarding this model based on transmission line theory is lacking" and that deviations between experimental absorption peaks and QWM predictions are common, with "no universal and reasonable theoretical explanation"[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Neglect of Interface Phase Effects

QWM is fundamentally flawed because it ignores the phase effects of interfaces within films[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). The theory incorrectly assumes that absorption minima occur at d = (2n + 1)λ/4, but this fails particularly for magnetic materials at high frequencies, where minima actually occur at d = nλ/2[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Misconceptions About Microwave Heating Mechanisms

The Dipole Rotation Myth

Current theories oversimplify microwave heating by focusing solely on dipole rotation of water molecules[5](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[6](https://physics.stackexchange.com/questions/602336/microwaves-why-do-they-cook-food). However, this mechanism is not a resonant process[7](http://ffden-2.phys.uaf.edu/211_fall2013.web.dir/Zackery_Schikora/Domestic%20use/domesticuse.html). Microwave ovens operate at 2.45 GHz, but the lowest energy transitions of water molecules are rotational transitions in the 100 GHz to 1 THz range[7](http://ffden-2.phys.uaf.edu/211_fall2013.web.dir/Zackery_Schikora/Domestic%20use/domesticuse.html). The photon energy in microwave ovens is too low for any resonant absorption[7](http://ffden-2.phys.uaf.edu/211_fall2013.web.dir/Zackery_Schikora/Domestic%20use/domesticuse.html).

Not a "Heating" Process

From a thermodynamics perspective, microwave cooking is not actually a "heating" process in the technical sense[5](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[6](https://physics.stackexchange.com/questions/602336/microwaves-why-do-they-cook-food). Heat refers to energy transfer due solely to temperature difference, but microwave energy transfer to food is actually work performed by the alternating electric field on molecular dipoles[5](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[6](https://physics.stackexchange.com/questions/602336/microwaves-why-do-they-cook-food). Since the "temperature" of microwaves is only a few degrees Kelvin, there is no heat transfer from microwaves to food[5](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm).

Friction and Collision Requirements

The simple explanation that microwaves cause water molecules to vibrate and directly heat food is incomplete[8](https://www.sciencedirect.com/science/article/abs/pii/S0304885324001410). While microwaves do twist water molecules back and forth, this twisting alone doesn't make them hot[8](https://www.sciencedirect.com/science/article/abs/pii/S0304885324001410). In gaseous steam, microwaves twist water molecules but don't heat them because the molecules simply re-emit the microwaves[8](https://www.sciencedirect.com/science/article/abs/pii/S0304885324001410). Only in liquid water, where molecules can rub against each other during twisting, are the microwaves permanently absorbed and converted to thermal energy[8](https://www.sciencedirect.com/science/article/abs/pii/S0304885324001410).

The Correct Alternative: Wave Cancellation Theory

Energy Conservation Approach

Wave cancellation theory (WCT) provides a more accurate explanation based on energy conservation principles specific to films[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). This theory recognizes that reflection loss is determined by the cancellation of two reflected beams: one reflected from the front interface (beam 1r) and another transmitted beam (beam t) resulting from multiple internal reflections[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Phase Difference as the Key Factor

The angular effect from the phase difference between these beams is vital for understanding microwave absorption[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). Most efficient absorption occurs when beams are out of phase by π (φ = (2n + 1)π), leading to wave cancellation, while least absorption occurs when beams are in phase (φ = 2nπ)[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Stronger Transmitted Beams for Better Absorption

Contrary to IM theory, WCT demonstrates that the strongest transmitted beam provides the most efficient absorption[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). When beams are out of phase for optimal absorption, the transmitted beam must be strong enough to cancel the reflected beam, requiring more back-and-forth reflections within the film[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Implications for Materials Science and Engineering

Experimental Data Reinterpretation

These theoretical flaws mean that decades of published experimental data supporting IM and QWM may need reinterpretation[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf). The apparent "support" for wrong theories follows historical patterns where incorrect models were seemingly validated by experiments until proven wrong[4](https://sci-hub.se/downloads/2020-07-13/23/gao2020.pdf).

Design and Development Impact

The confusion between films and materials has led to the development of wrong concepts in materials design, including flawed impedance matching criteria and incorrect absorption mechanisms[2](https://www.qeios.com/read/ZKKEZF)[3](https://arxiv.org/ftp/arxiv/papers/1406/1406.1847.pdf). This affects the development of microwave-absorbing materials for applications ranging from stealth technology to electromagnetic compatibility.

Conclusion

Current microwave absorption theories are fundamentally flawed due to conceptual confusion between films and materials, lack of rigorous theoretical foundations, mathematical errors, and oversimplified heating mechanisms. The wave cancellation theory offers a more physics-based approach that aligns with energy conservation principles and experimental observations. Recognizing these errors is crucial for advancing our understanding of microwave interactions with matter and developing more effective microwave-absorbing technologies.

**Relacionado**

Why do current microwave absorption theories confuse film and material properties

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Why Current Microwave Absorption Theories Confuse Film and Material Properties

Current microwave absorption theories suffer from a fundamental conceptual error that has plagued the field for decades: the confusion between films and materials[1](https://www.qeios.com/read/ZKKEZF)[2](https://www.qeios.com/read/QQ1MFF)[3](https://www.qeios.com/read/QQ1MFF/pdf). This confusion has led to widespread misapplication of theoretical principles, incorrect interpretation of experimental data, and the development of flawed absorption mechanisms that fail to accurately describe the physics involved.

The Fundamental Distinction Between Films and Materials

What Are Films vs. Materials?

Films are devices composed of materials with specific geometric properties - they have two parallel interfaces and a defined thickness that creates unique electromagnetic behavior[1](https://www.qeios.com/read/ZKKEZF)[3](https://www.qeios.com/read/QQ1MFF/pdf). Materials, on the other hand, are substances characterized by their intrinsic electromagnetic properties such as permittivity (εᵣ) and permeability (μᵣ)[3](https://www.qeios.com/read/QQ1MFF/pdf)[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). This distinction is crucial because films exhibit behavior that results from wave interference effects between their interfaces, which simply cannot occur in uniform bulk materials[1](https://www.qeios.com/read/ZKKEZF)[5](https://ib-lenhardt.com/kb/glossary/return-loss).

Films create multiple reflected beams due to back-and-forth reflections between their interfaces, generating complex wave interference patterns[3](https://www.qeios.com/read/QQ1MFF/pdf)[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). In contrast, when microwaves propagate through bulk materials, they experience monotonic amplitude decay without the formation of absorption peaks[3](https://www.qeios.com/read/QQ1MFF/pdf)[5](https://ib-lenhardt.com/kb/glossary/return-loss). The absorption behavior of films is fundamentally different from the attenuation power of their constituent materials[5](https://ib-lenhardt.com/kb/glossary/return-loss).

The Physics Behind the Difference

The absorption mechanisms are fundamentally different between films and materials[6](https://www.sciencedirect.com/science/article/abs/pii/S2468023023003929)[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). For materials, microwave absorption increases monotonically as waves travel further into the medium - more microwaves are absorbed when they travel greater distances through the material[1](https://www.qeios.com/read/ZKKEZF)[6](https://www.sciencedirect.com/science/article/abs/pii/S2468023023003929). However, for films, the situation is entirely different: absorption can actually decrease when film thickness is increased, creating a wave-like function with distinct peaks and minima[1](https://www.qeios.com/read/ZKKEZF)[6](https://www.sciencedirect.com/science/article/abs/pii/S2468023023003929)[5](https://ib-lenhardt.com/kb/glossary/return-loss).

This difference arises because film absorption is determined by wave mechanics and interference effects rather than simple material attenuation[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). The absorption curve for films possesses a wave form that signifies the absorption from the film is very different from the attenuation power of the material[5](https://ib-lenhardt.com/kb/glossary/return-loss).

Misapplication of Reflection Loss Parameters

The Core Problem with RL Usage

One of the most significant manifestations of this confusion is the widespread misuse of reflection loss (RL) parameters[1](https://www.qeios.com/read/ZKKEZF)[2](https://www.qeios.com/read/QQ1MFF)[3](https://www.qeios.com/read/QQ1MFF/pdf). Reflection loss RL is a parameter specifically designed to characterize metal-backed films - it describes the behavior of devices, not materials[3](https://www.qeios.com/read/QQ1MFF/pdf)[7](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4797207). However, current theories incorrectly apply RL to characterize the absorption properties of materials themselves[1](https://www.qeios.com/read/ZKKEZF)[2](https://www.qeios.com/read/QQ1MFF)[3](https://www.qeios.com/read/QQ1MFF/pdf).

This misapplication has created a fundamental error in how researchers interpret experimental data[3](https://www.qeios.com/read/QQ1MFF/pdf)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations). Return loss is expressed in decibels (dB) and represents the ratio of incident to reflected power, quantifying how much power is reflected back from a device or component in a transmission line[9](https://www.qeios.com/read/ZKKEZF/pdf). When properly used, RL characterizes the absorption from metal-backed films, but it should never be used to describe material properties[3](https://www.qeios.com/read/QQ1MFF/pdf)[7](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4797207).

Interface vs. Film Confusion

Adding to this confusion, researchers have incorrectly used the reflection coefficient of interfaces (RM) to characterize absorption in films[3](https://www.qeios.com/read/QQ1MFF/pdf). This is fundamentally wrong because interfaces do not absorb microwaves - they only reflect or transmit them[3](https://www.qeios.com/read/QQ1MFF/pdf). The absorption mechanism involves the film as a whole device, not individual interfaces within it[3](https://www.qeios.com/read/QQ1MFF/pdf)[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751).

Problems with Current Theoretical Frameworks

Impedance Matching Theory Failures

The confusion between films and materials has led to the development of flawed impedance matching theory (IM)[1](https://www.qeios.com/read/ZKKEZF)[10](https://www.telecomtrainer.com/rl-return-loss/)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations). This theory incorrectly assumes that optimal absorption occurs when the input impedance of the film equals the characteristic impedance of free space[1](https://www.qeios.com/read/ZKKEZF). However, experimental data consistently contradicts IM predictions across entire frequency ranges[1](https://www.qeios.com/read/ZKKEZF).

The theory suffers from fundamental mathematical errors, including treating complex impedances as real numbers and ignoring critical phase relationships[1](https://www.qeios.com/read/ZKKEZF). Impedance matching refers to transforming impedances in transmission line systems, but the application to microwave absorption has been fundamentally misunderstood[11](https://pubmed.ncbi.nlm.nih.gov/23815370/).

Quarter-Wavelength Theory Issues

Similarly, quarter-wavelength theory (QWM) lacks rigorous theoretical proof and fails to account for the actual physics of wave interactions in films[1](https://www.qeios.com/read/ZKKEZF)[2](https://www.qeios.com/read/QQ1MFF). The theory incorrectly assumes specific relationships between thickness and wavelength that don't hold for the complex wave interference occurring in films[1](https://www.qeios.com/read/ZKKEZF).

The Correct Wave Cancellation Approach

Energy Conservation and Wave Mechanics

The correct understanding comes from wave cancellation theory (WCT), which recognizes that film absorption is determined by the cancellation of two reflected beams[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). One beam reflects from the front interface, while another results from multiple internal reflections and transmission through the film[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751)[5](https://ib-lenhardt.com/kb/glossary/return-loss).

The reflection loss value is determined by energy conservation principles specific to films, related to the amplitude of the resultant of these two beams[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). The angular effect from the phase difference between the beams is vital for understanding microwave absorption from films[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751)[5](https://ib-lenhardt.com/kb/glossary/return-loss).

Phase Relationships and Interference

Most efficient absorption occurs when the beams are out of phase by π (φ = (2n + 1)π), leading to destructive interference and wave cancellation[1](https://www.qeios.com/read/ZKKEZF)[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751). Conversely, least absorption occurs when beams are in phase (φ = 2nπ), resulting in constructive interference[1](https://www.qeios.com/read/ZKKEZF). This wave mechanics approach provides a physics-based explanation that aligns with experimental observations[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751)[10](https://www.telecomtrainer.com/rl-return-loss/).

Impact on Materials Science and Research

Misguided Research Directions

The confusion between films and materials has directed research efforts toward exploring wrong concepts[3](https://www.qeios.com/read/QQ1MFF/pdf)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations). Researchers have inappropriately attributed properties of materials - such as dielectric and magnetic loss tangents, conductivity, and polarization - as reasons for absorption peaks in films[3](https://www.qeios.com/read/QQ1MFF/pdf). In reality, these peaks result from film properties that force the constituent material to absorb specific amounts of microwaves, rather than material properties determining film absorption[3](https://www.qeios.com/read/QQ1MFF/pdf).

Experimental Data Misinterpretation

This theoretical confusion has led to decades of published experimental data being used to support incorrect theories[3](https://www.qeios.com/read/QQ1MFF/pdf)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations). The apparent "validation" of wrong theories through experimental data follows historical patterns where flawed models seemed to work until proven incorrect[1](https://www.qeios.com/read/ZKKEZF). Many publications have mixed up parameters for interfaces and films, leading to fundamental errors in analysis[3](https://www.qeios.com/read/QQ1MFF/pdf).

Consequences for the Field

The confusion between films and materials has created a cascade of problems in microwave absorption research[1](https://www.qeios.com/read/ZKKEZF)[2](https://www.qeios.com/read/QQ1MFF)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations). It has led to the establishment of wrong absorption mechanisms, incorrect impedance matching criteria, and flawed design principles for microwave-absorbing materials[1](https://www.qeios.com/read/ZKKEZF)[3](https://www.qeios.com/read/QQ1MFF/pdf). This affects applications ranging from electromagnetic compatibility to stealth technology development[1](https://www.qeios.com/read/ZKKEZF).

The field needs to recognize that film absorption is fundamentally different from material absorption, requiring wave mechanics approaches rather than simple attenuation models[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751)[10](https://www.telecomtrainer.com/rl-return-loss/)[5](https://ib-lenhardt.com/kb/glossary/return-loss). Only by correcting this fundamental confusion can microwave absorption theory advance to accurately describe the underlying physics and enable more effective material and device design[1](https://www.qeios.com/read/ZKKEZF)[4](https://www.sciencedirect.com/science/article/abs/pii/S0921452623004751)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations).

Understanding this distinction is crucial for developing more accurate theories and more effective microwave-absorbing technologies, moving beyond the current flawed frameworks that have dominated the field for too long[1](https://www.qeios.com/read/ZKKEZF)[10](https://www.telecomtrainer.com/rl-return-loss/)[8](https://phys.libretexts.org/Courses/Berea_College/Electromagnetics_I/03:_Transmission_Lines/3.21:_Impedance_Matching_-_General_Considerations).

**Relacionado**

How does the misinterpretation of physical processes lead to incorrect microwave absorption models

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[sciencedirect](https://www.sciencedirect.com/science/article/abs/pii/S0254058422008276" \t "_blank)

[A re-evaluation of the mechanism of microwave absorption in film](https://www.sciencedirect.com/science/article/abs/pii/S0254058422008276" \t "_blank)

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[qeios](https://www.qeios.com/read/ZKKEZF/pdf" \t "_blank)

[Review of Wave Mechanics Theory for Microwave Absorption by Film](https://www.qeios.com/read/ZKKEZF/pdf" \t "_blank)

How Misinterpretation of Physical Processes Leads to Incorrect Microwave Absorption Models

The misinterpretation of fundamental physical processes has created a cascade of errors in microwave absorption theory, leading to widely accepted but fundamentally flawed models that persist in scientific literature. These misconceptions stem from several key areas: confusion between different physical systems, oversimplified heating mechanisms, incorrect quantum mechanical assumptions, and misapplication of wave physics principles.

Fundamental Confusion Between Films and Materials

The Core Conceptual Error

One of the most significant sources of error is the widespread confusion between films and materials in microwave absorption theory[1](https://www.qeios.com/read/QQ1MFF)[2](https://www.sciencedirect.com/science/article/abs/pii/S2468023023003929)[3](https://www.sciencedirect.com/science/article/abs/pii/S0254058422008276). Films are devices with specific geometric properties—two parallel interfaces and defined thickness—that create unique electromagnetic behavior through wave interference effects[4](https://www.qeios.com/read/ZKKEZF/pdf). Materials, in contrast, are substances characterized by intrinsic electromagnetic properties like permittivity and permeability[1](https://www.qeios.com/read/QQ1MFF)[5](https://www.qeios.com/read/QQ1MFF/pdf).

This distinction is crucial because films exhibit behavior that results from back-and-forth reflections between interfaces, generating complex wave interference patterns that simply cannot occur in uniform bulk materials[4](https://www.qeios.com/read/ZKKEZF/pdf)[5](https://www.qeios.com/read/QQ1MFF/pdf). When microwaves propagate through bulk materials, they experience monotonic amplitude decay, while films can actually show decreased absorption when thickness increases, creating wave-like functions with distinct peaks and minima[1](https://www.qeios.com/read/QQ1MFF)[4](https://www.qeios.com/read/ZKKEZF/pdf).

Misapplication of Reflection Loss Parameters

The confusion has led to the incorrect use of reflection loss (RL) parameters, which are specifically designed to characterize metal-backed films, being applied to describe material properties[1](https://www.qeios.com/read/QQ1MFF)[5](https://www.qeios.com/read/QQ1MFF/pdf). This fundamental error has resulted in researchers incorrectly attributing absorption peaks in layered materials to the material itself rather than to the wave interference effects specific to film geometry[4](https://www.qeios.com/read/ZKKEZF/pdf)[5](https://www.qeios.com/read/QQ1MFF/pdf).

Return loss is a parameter that quantifies how much power is reflected back from a device in a transmission line, expressed in decibels[4](https://www.qeios.com/read/ZKKEZF/pdf). When properly used, RL characterizes absorption from metal-backed films, but it should never be used to describe intrinsic material properties[1](https://www.qeios.com/read/QQ1MFF)[5](https://www.qeios.com/read/QQ1MFF/pdf). This misapplication has created decades of published experimental data that seemingly supports incorrect theories[4](https://www.qeios.com/read/ZKKEZF/pdf).

Oversimplified and Incorrect Heating Mechanisms

The Dipole Rotation Myth

Current theories oversimplify microwave heating by focusing solely on dipole rotation of water molecules, but this mechanism is not actually a resonant process[6](https://www.moreisdifferent.com/2013/07/14/a-misconception-about-microwaves/)[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/). A widespread misconception claims that microwave ovens operate at a frequency specifically tuned to water molecule resonances, but this is demonstrably false[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/)[8](https://howeverythingworks.org/1999/11/02/question-1456/). The actual vibrational frequencies of water molecules are in the infrared range: symmetric and asymmetric stretching modes occur around 108 THz, while the bending mode occurs at 45 THz—frequencies that are 1000 times higher than microwave frequencies[6](https://www.moreisdifferent.com/2013/07/14/a-misconception-about-microwaves/)[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/).

Microwave ovens operate at 2.45 GHz not because this frequency matches any water resonance, but because it was allocated by regulatory agencies as allowable for microwave oven usage and provides good penetration into foods[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/)[8](https://howeverythingworks.org/1999/11/02/question-1456/). The photon energy in microwave ovens is too low for any resonant absorption—microwaves simply expose water molecules to intense electromagnetic fields that cause non-resonant dielectric heating[9](https://www.tdk.com/en/tech-mag/inductive/how-does-a-microwave-oven-work)[10](https://cem.com/microwave-heating-mechanism-and-theory)[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/).

Thermodynamic Misconceptions

From a thermodynamics perspective, microwave cooking is technically not a "heating" process in the strict sense[11](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[12](https://physics.stackexchange.com/questions/602336/microwaves-why-do-they-cook-food). Heat, by definition, refers to energy transfer due solely to temperature difference[11](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[13](https://www.numberanalytics.com/blog/ultimate-guide-thermodynamic-heat). However, microwave energy transfer to food is actually work performed by the alternating electric field on molecular dipoles[11](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[12](https://physics.stackexchange.com/questions/602336/microwaves-why-do-they-cook-food). Since the "temperature" of microwaves is only a few degrees Kelvin, there is no actual heat transfer from microwaves to food—the process involves work transfer that gives dipoles rotational kinetic energy[11](https://physics.stackexchange.com/questions/515917/why-are-there-different-explanations-of-microwave-oven-heating-eg-dipole-alignm)[12](https://physics.stackexchange.com/questions/602336/microwaves-why-do-they-cook-food).

The simple explanation that microwaves cause water molecules to vibrate and directly heat food is incomplete[14](https://crescendrf.com/microwave-myths-debunked/)[15](https://researchmap.jp/read0053111/published_papers/1318110/attachment_file.pdf). In gaseous steam, microwaves can twist water molecules but don't heat them because the molecules simply re-emit the microwaves[14](https://crescendrf.com/microwave-myths-debunked/). Only in liquid water, where molecules can collide and rub against each other during twisting, are the microwaves permanently absorbed and converted to thermal energy through friction and collisions[14](https://crescendrf.com/microwave-myths-debunked/)[15](https://researchmap.jp/read0053111/published_papers/1318110/attachment_file.pdf).

Incorrect Quantum Mechanical and Resonance Assumptions

Photon Energy Misunderstandings

A fundamental error in many explanations involves claiming that microwave photons have the correct energy to excite molecular vibrations[6](https://www.moreisdifferent.com/2013/07/14/a-misconception-about-microwaves/)[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/)16. In reality, microwave photon energy is relatively low (0.03–0.00003 kcal/mol) and affects only kinetic molecular excitation[10](https://cem.com/microwave-heating-mechanism-and-theory). The lowest energy transitions of water molecules are rotational transitions in the 100 GHz to 1 THz range, not at the 2.45 GHz frequency used in microwave ovens[6](https://www.moreisdifferent.com/2013/07/14/a-misconception-about-microwaves/)[7](https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/).

Molecular dynamics simulations have shown that water molecules exhibit rotational motion whose average phase is delayed from the microwave electric field, and microwave energy is transferred to both kinetic and intermolecular energies, where about one-third of absorbed microwave energy is stored as intermolecular energy[17](https://pubs.rsc.org/en/content/articlelanding/2023/cp/d3cp00349c/unauth)[15](https://researchmap.jp/read0053111/published_papers/1318110/attachment_file.pdf).

Frequency-Dependent Effects Ignored

Research has revealed a remarkably strong dependence of vibrational relaxation time on the frequency of OH stretching vibrations in liquid water[18](https://www.nature.com/articles/ncomms9384). For bulk water, vibrational relaxation time increases continuously from 250 to 550 femtoseconds when frequency increases from 3,100 to 3,700 cm⁻¹[18](https://www.nature.com/articles/ncomms9384). This frequency dependence demonstrates substantial structural heterogeneity in liquid water that is not accounted for in simplified models[18](https://www.nature.com/articles/ncomms9384).

Flawed Wave Physics and Interference Models

Impedance Matching Theory Failures

Impedance matching theory (IM) incorrectly assumes that optimal absorption occurs when the input impedance of a film equals the characteristic impedance of free space[1](https://www.qeios.com/read/QQ1MFF)[3](https://www.sciencedirect.com/science/article/abs/pii/S0254058422008276)[4](https://www.qeios.com/read/ZKKEZF/pdf). However, experimental data consistently contradicts IM predictions across entire frequency ranges[3](https://www.sciencedirect.com/science/article/abs/pii/S0254058422008276)[4](https://www.qeios.com/read/ZKKEZF/pdf). The theory suffers from fundamental mathematical errors, including treating complex impedances as real numbers and ignoring critical phase relationships[4](https://www.qeios.com/read/ZKKEZF/pdf).

The theory incorrectly claims that maximum absorption occurs when both reflected beams vanish simultaneously, but for films, even when input impedance equals free space impedance, individual reflected beams still exist and cancel each other out through wave interference—they don't simply disappear[4](https://www.qeios.com/read/ZKKEZF/pdf)[5](https://www.qeios.com/read/QQ1MFF/pdf).

Quarter-Wavelength Theory Problems

Quarter-wavelength theory (QWM) lacks rigorous theoretical proof based on transmission-line theory and fails to account for the actual physics of wave interactions in films[3](https://www.sciencedirect.com/science/article/abs/pii/S0254058422008276)[4](https://www.qeios.com/read/ZKKEZF/pdf). The theory incorrectly assumes specific relationships between thickness and wavelength that don't hold for the complex wave interference occurring in films[1](https://www.qeios.com/read/QQ1MFF)[4](https://www.qeios.com/read/ZKKEZF/pdf). Deviations between experimental absorption peaks and QWM predictions are common, with no universal theoretical explanation for these discrepancies[4](https://www.qeios.com/read/ZKKEZF/pdf).

Misunderstanding of Wave Cancellation

The correct understanding requires recognizing that film absorption is determined by the cancellation of two reflected beams: one reflected from the front interface and another resulting from multiple internal reflections[4](https://www.qeios.com/read/ZKKEZF/pdf)[19](https://en.wikipedia.org/wiki/Thin-film_interference)[20](https://en.wikipedia.org/wiki/Wave_interference). Wave interference—both constructive and destructive—is fundamental to understanding electromagnetic wave behavior[20](https://en.wikipedia.org/wiki/Wave_interference)[21](http://www.electricity-magnetism.org/principle-of-superposition/).

Most efficient absorption occurs when beams are out of phase by π (φ = (2n + 1)π), leading to destructive interference and wave cancellation[4](https://www.qeios.com/read/ZKKEZF/pdf)[20](https://en.wikipedia.org/wiki/Wave_interference). Conversely, least absorption occurs when beams are in phase (φ = 2nπ), resulting in constructive interference[4](https://www.qeios.com/read/ZKKEZF/pdf)[20](https://en.wikipedia.org/wiki/Wave_interference). This wave mechanics approach provides a physics-based explanation that aligns with experimental observations, unlike the flawed impedance matching approaches[4](https://www.qeios.com/read/ZKKEZF/pdf).

Misinterpretation of Dielectric Loss Mechanisms

Confusion About Loss Tangent

Current theories often misinterpret dielectric loss as simply related to material properties, when in reality, dielectric losses are particularly high around relaxation or resonance frequencies of polarization mechanisms[22](https://www.vedantu.com/physics/dielectric-loss). The polarization lags behind the applied field, resulting in interaction between the field and the dielectric's polarization that leads to heating[22](https://www.vedantu.com/physics/dielectric-loss).

For microwave ovens, the frequency used is deliberately chosen to be slightly away from the frequency at which maximum dielectric loss occurs in water to ensure that microwaves are not all absorbed by the first layer of water they encounter, allowing proper heating throughout the food[22](https://www.vedantu.com/physics/dielectric-loss). This practical consideration is often overlooked in theoretical treatments.

Interface vs. Film Properties

Adding to the confusion, researchers have incorrectly used reflection coefficients of interfaces to characterize absorption in films[1](https://www.qeios.com/read/QQ1MFF)[4](https://www.qeios.com/read/ZKKEZF/pdf). This is fundamentally wrong because interfaces do not absorb microwaves—they only reflect or transmit them[4](https://www.qeios.com/read/ZKKEZF/pdf). The absorption mechanism involves the film as a whole device, not individual interfaces within it[1](https://www.qeios.com/read/QQ1MFF)[4](https://www.qeios.com/read/ZKKEZF/pdf).

Consequences and Impact on Scientific Understanding

Experimental Data Misinterpretation

These theoretical flaws mean that decades of published experimental data supporting impedance matching and quarter-wavelength theories may need reinterpretation[4](https://www.qeios.com/read/ZKKEZF/pdf)[5](https://www.qeios.com/read/QQ1MFF/pdf). The apparent "validation" of wrong theories through experimental data follows historical patterns where incorrect models seemed to work until proven wrong[4](https://www.qeios.com/read/ZKKEZF/pdf)[5](https://www.qeios.com/read/QQ1MFF/pdf).

Measurements of millimeter wave absorption by thin films have shown that reflection and absorption can significantly differ from behavior in similar semi-infinite media, with absorption passing through multiple maxima and minima as film thickness changes[23](https://pubmed.ncbi.nlm.nih.gov/10797455/). These experimental observations support wave interference explanations rather than simple material attenuation models[23](https://pubmed.ncbi.nlm.nih.gov/10797455/).

Design and Development Problems

The misinterpretation of physical processes has led to the development of incorrect concepts in materials design, including flawed impedance matching criteria and incorrect absorption mechanisms[1](https://www.qeios.com/read/QQ1MFF)[4](https://www.qeios.com/read/ZKKEZF/pdf). This affects applications ranging from electromagnetic compatibility to stealth technology development, where understanding the true physics of microwave interaction is crucial for effective design[24](https://pubs.rsc.org/en/content/articlelanding/2023/mh/d3mh01368e/unauth)[25](https://www.frontiersin.org/articles/10.3389/fmats.2023.1133287/full).

The Need for Correct Wave Mechanics Approaches

The solution lies in adopting wave cancellation theory (WCT), which provides a more accurate explanation based on energy conservation principles specific to films[4](https://www.qeios.com/read/ZKKEZF/pdf). This approach recognizes that reflection loss is determined by wave superposition and interference effects rather than simple impedance matching or material attenuation[4](https://www.qeios.com/read/ZKKEZF/pdf)[20](https://en.wikipedia.org/wiki/Wave_interference).

Understanding wave interference in thin films—where waves reflected from upper and lower boundaries interfere with one another—provides the correct physical foundation for microwave absorption[19](https://en.wikipedia.org/wiki/Thin-film_interference)[26](https://korvustech.com/thin-film-interference/). Perfect absorption can be achieved through wave cancellation, where secondary waves perfectly cancel both forward and backward propagating waves[27](https://physics.aps.org/articles/v16/196).

The misinterpretation of these fundamental physical processes has created a web of interconnected errors that have persisted in microwave absorption theory for decades. Only by recognizing and correcting these misconceptions—from the basic distinction between films and materials to the proper understanding of wave interference and thermodynamic processes—can the field advance toward more accurate theoretical frameworks and more effective practical applications.

Relacionado

How does misinterpreting dielectric and magnetic losses distort absorption models

Why do incorrect assumptions about molecular dipole rotation lead to flawed theories

How can errors in understanding ferromagnetic resonance affect microwave absorption predictions

In what ways do oversimplified models overlook complex interference effects in layered structures

How does neglecting the true physical processes cause inaccuracies in broadband absorption models

**Note by the authors:**

It should be noted that microwave absorption of film can be revealed by wave mechanics theory and the absorption peaks of the film are determined by wave cancellation.