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Material Characterization of Graphene Oxide and Reduced Graphene Oxide Using Resonance Methods

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STATUS QUO

GrInShield for Twinning for new graphene based composites in EM shielding

•**Graphene-based materials** (GO & rGO) are critical for emerging tech: sensors, flexible electronics, energy devices.

•Their **electromagnetic properties** (dielectric permittivity, conductivity, resistivity) are **highly variable** and **difficult to characterize**.

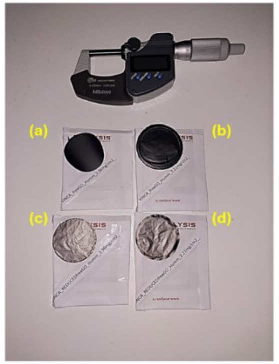
•Traditional methods **lack accuracy**, especially at **high frequencies**.

•**Advanced, non-destructive** techniques are needed to extract precise material parameters for reliable application.

NEW INSIGHTS

- ✓ **Chemical reduction** of GO using ascorbic acid leads to **structural changes**, confirmed by reduced thickness (oxygen group removal).
- ✓ **Mass density** impacts dielectric properties — higher density enhances **polarization** and **energy dissipation** (SPDR results).
- ✓ **Conductivity of rGO** increased significantly, reaching **572.24 S/m** (SiPDR), confirming effective restoration of electrical pathways.
- ✓ Highlights a **green, efficient reduction strategy** for tuning GO/rGO in electronic and sensing applications.
- ✓ Uses retro-modeling: combines simulation + signal processing for high-precision data extraction.
- ✓ Enables tailored optimization of recycled GO/rGO for real-world applications across electronics & sensing.

DESCRIPTION



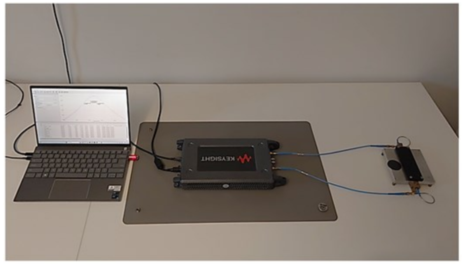
Graphene oxide (GO) was synthesized via a modified Hummers method, involving the controlled oxidation of graphite in sulfuric acid with potassium permanganate. The resulting GO was purified through centrifugation and dialysis, then dispersed in water and deposited via vacuum filtration to create films with mass densities of 1.96 and 2.21 mg/cm². Reduced graphene oxide (rGO) was obtained by chemically reducing GO with ascorbic acid, followed by rinsing and drying.

(a) GO 1.96 mg/cm²
(b) GO 2.21 mg/cm²
(c) rGO 1.96 mg/cm²
(d) rGO 2.21 mg/cm²

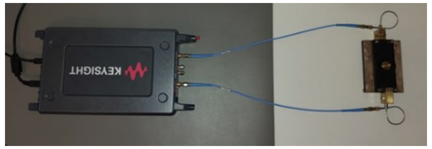
MEASUREMENT METHODS

This **S**ingle–**P**ost **D**ielectric **R**esonator operates at **5 GHz** and is optimized for samples where loss mechanisms dominate, such as those with significant conductivity.
This method is particularly effective for:
•**Highly lossy materials**
•**Thin films** or **composites** with conductive inclusions (e.g., graphene nanoplatelets, CNTs, metallic powders)

It is widely used in the **semiconductor industry** to assess both intrinsic and doped materials.



GO and rGO samples under test on 5GHz SiPDR measurement setup which also included a VNA and a laptop with dedicated software.



GO and rGO samples were prepared for mm-wave characterization.

This **S**plit **P**ost **D**ielectric **R**esonator operates at a higher frequency of **10 GHz** and is tailored for thin dielectric and conductive polymer films with high surface resistance (>5 kΩ/sq). It provides **High measurement accuracy** (error typically <0.3%).

SPDRs are ideal for evaluating:
•**High-resistivity semiconductors**
•**Ferroelectric layers**
•**Low-temperature co-fired ceramics**

QUANTITATIVE IMPACT

Results of GO/rGO samples measured on 5 GHz SiPDR and 10 GHz SPDR.

Sample	ε (SPDR)	tanδ (SPDR)	Resistivity [OhmCm] (SiPDR)	Conductivity [S/m] 5 GHz SiPDR	Conductivity [S/m] 10 GHz SPDR
GO 1.96 mg/cm²	6.75	0.0153	1307.3400	0.0765	0.0579
GO 2.21 mg/cm²	7.36	0.0352	648.1760	0.1543	0.1454
rGO 1.96 mg/cm²	—	—	0.4733	211.2744	—
rGO 2.21 mg/cm²	—	—	0.1748	572.2395	—

•Higher mass density (2.21 mg/cm²) led to **increased dielectric constant** and **loss tangent**, indicating enhanced **polarization** and **energy dissipation**.

•**Sharp rise in conductivity**:
•*1.96 mg/cm²:* **0.0765 S/m → 211.27 S/m**
•*2.21 mg/cm²:* **→ 572.24 S/m**

• **Massive drop in resistivity** post-reduction:
•*1.96 mg/cm²:* from **1307.34 Ω·cm → 0.4733 Ω·cm**
•*2.21 mg/cm²:* from **648.18 Ω·cm → 0.1748 Ω·cm**

PROPOSED CONCEPT GOALS

•Optimize Electrical Properties Through Reduction
Use chemical reduction (e.g., with ascorbic acid) to improve conductivity of GO by removing oxygen functional groups, transforming it into high-performance rGO.

•Tailor Material for High-Frequency Applications
Leverage improved rGO properties for use in mm-wave technologies, antennas, sensors, and EMI shielding.

•Correlate Processing with Performance
Analyze how synthesis and reduction influence structural and electromagnetic behavior, including penetration depth and dielectric loss.

•Expand Material Range for Broader Insight
Extend characterization to rGO and GO samples with varying mass densities for deeper understanding of property-performance relationships.

Future work involves tasks in projects: I4Bags 5GFoil