Methods and Systems for Determining Optical Properties of Materials Using Casimir Interactions

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ABSTRACT

Researchers at the University of California, Davis have developed methods that leverage measured Casimir interactions combined with machine learning to accurately determine broadband optical properties of materials without direct optical excitation.

FULL DESCRIPTION

This technology employs measurements of Casimir forces, which originate from quantum electromagnetic fluctuations, between a reference material with known optical properties and a target material with unknown properties across various separation distances. Using a physically grounded forward model based on Lifshitz theory and machine learning inverse mapping, it reconstructs the complex permittivity, capturing both real and imaginary components of the material's dielectric response over a broad frequency spectrum. This approach uniquely exploits the spectral sensitivity variation of Casimir interactions at different distances to enable selective probing of material optical characteristics, circumventing the need for direct optical methods and providing access to challenging frequency regimes.

APPLICATIONS

- Materials science and engineering for comprehensive optical characterization.
- Nanotechnology and photonics device design and optimization.
- Quality control in manufacturing processes requiring precision optical material properties.
- Fundamental research in quantum electrodynamics and dispersion forces.
- Development of sensors and measurement tools based on Casimir interaction measurements.
- Enhancement of computational models predicting electromagnetic material interactions.
- Integration in atomic force microscopy and microelectromechanical systems for advanced metrology.

FEATURES/BENEFITS

- Enables broadband optical property reconstruction without requiring direct optical excitation.
- Probes low-frequency spectral regimes inaccessible to conventional spectroscopy.
- Reduces uncertainties and improves consistency by applying physically constrained inverse modeling.
- Applies to diverse materials, geometries, and platforms using existing Casimir force measurement setups.

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OTHER INFORMATION

KEYWORDS

atomic force microscopy, broadband optical spectroscopy, casimir force, dielectric response, inverse problem, machine learning, permittivity reconstruction, quantum electromagnetic fluctuations, spectrally weighted spectroscopy, wide frequency range

CATEGORIZED AS

- **Optics and Photonics**
  - All Optics and Photonics

- Selectively probes spectral regions by adjusting distance-dependent sensitivity of Casimir interactions.
- Enhances efficiency and accuracy with machine learning-driven inverse problem solving.
- Minimizes reliance on concatenated datasets and ad hoc extrapolations typical in traditional methods.
- Overcomes challenges in characterizing optical properties at very low frequencies with standard spectroscopy.
- Eliminates inconsistencies and uncertainties from concatenating disparate optical datasets.
- Removes the need for direct optical excitation in measurement approaches.
- Solves the intractability of analytically inverting Casimir force measurements to obtain optical properties.
- Reconstructs broadband dielectric responses from limited experimental data.
- Fills the gap for general frameworks that integrate quantum electrodynamics with data-driven inversion techniques.

- **Materials & Chemicals**
  - Nanomaterials
- **Nanotechnology**
  - Materials
- **Sensors & Instrumentation**
  - Physical Measurement

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