Understanding Novel Physical Properties of One-Dimensional Disordered Hyperuniform Metamaterials

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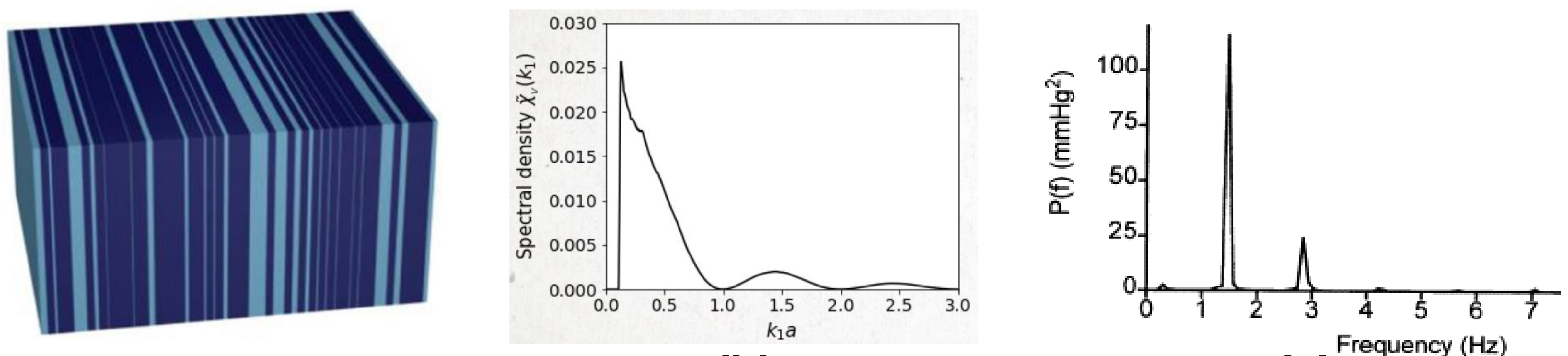
Introduction

Disordered hyperuniformity (DHU) is a newly discovered state of matter that possess exciting and unique physical properties. It most closely resembles an amorphous material, appearing to have no long-range periodicity. However, DHU materials posses a large-scale, hidden pattern that gives them both crystalline (wave interaction) and amorphous (isotropy and uniformity) properties. This research seeks to identify how DHU affects the wave properties of method and whether DHU has the capability to provide exciting new capabilities to security applications.

Results & Analysis



(a) **(b)** **(c)**

Figure 1: (a) Generated 1D DHU Metamaterial, (b) spectral density plot of a DHU system, (c) spectral density plot of an ordered system.

The results obtained from this research provided theoretical evidence that engineered DHU can impact the physical properties of a material in predictable ways. Figure (a) recreates DHU by utilizing a composite structure where two layers are interspaced at intervals that emulate naturally occurring DHU. Figure (b) indicates that the 1D metamaterial demonstrates amorphous properties despite being a composite of two crystalline materials. This is concludable due to smaller, more rounded spectral density peaks, which indicate a less ordered lattice configuration.

Research Progress

$$\frac{\varepsilon_e^{\perp}(k_1)}{\varepsilon_1} = 1 + \frac{\delta^{\perp}\phi_2^2}{\phi_2 - \delta^{\perp} F^{(1D)}\left(\sqrt{\varepsilon_e^{\perp}(0)}k_1\right)}$$

(d)

$$\delta^{\perp} \equiv \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_1}.$$

(e)

Figure 2: (d) Derived equation of spectral density utilizing:

- ε (permittivity)
- Φ (volume fraction of the black phase)
- $F^{(1D)}$ (function incorporating microstructure information)

(e) Contrast between the permittivity of two materials.

Much of the research was dedicated to determining what changed the level of disorder in DHU. The disorder in DHU was found to be introduced via the Spectral Density equation which was derived for this research (d). Furthermore, it was determined that $\delta^{\perp}$ (e) was what determined the level of disorder in a system and thus DHU properties.

Applications

Based on the properties of DHU, metamaterials could be engineered with improved light and energy transport properties. This could mean potential for wide band-gap materials and wave guides that are highly valued in military radar. Additionally, the isotropy of DHU materials would allow for many different possibilities in high end radar, an example being the possible creation of a receiver with a 360-degree arc of reception without need to rotate.

References

[1] Wood B, Pendry J B, Tsai D P. Directed subwavelength imaging using a layered metal-dielectric system[J]. Physical Review B, 2006, 74(11): 115116

[2] S. Torquato and J. Kim, Nonlocal Effective Electromagnetic Wave Characteristics of Composite Media: Beyond the Quasistatic Regime, Physical Review X, 11, 021002 (2021).

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