Design and fabrication of narrow band radar absorbing materials at terahertz frequencies

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ABSTRACT

The technique of tailoring the complex refractive index of an artificial dielectric material has been developed at the University of Lowell Research Foundation (ULRF). Low reflection coatings, generally referred to as Dällenbach layers, have been designed for metal substrates using the artificial dielectric. The method of characterizing materials for the purpose of tailoring their dielectric properties at terahertz frequencies will be discussed. Results will be shown for a typical dielectric coated aluminum plate specifically designed for low reflection behavior at ≈ 0.6 terahertz.

2. INTRODUCTION

Design of optical and quasi-optical measurement systems operating at terahertz frequencies require a wide range of materials for component fabrication. Critical to implementation of these laboratory systems are far-infrared radiation absorbing material (FIRAM) which may be used to suppress unwanted stray radiation. One type of FIRAM, known at microwave frequencies as the Dällenbach layer, consists of a metal substrate coated with an evenly thick homogeneous lossy dielectric material.[1] See figure 1.

Realization of the Dällenbach layer as FIRAM starts with ULRF's development of a particular class of submillimeter wavelength artificial dielectric, generically referred to as metallic paints. The paint, manufactured by Stainless Steel Coatings, Inc. of Littleton, Mass, consists of resins such as vinyl acetate, silicone or polyurethane uniformly loaded with stainless steel flakes. Since the metal flakes are dimensionally small compared to the wavelength, the paint exhibits optical properties of a homogeneous media which depend on the concentration of stainless steel flake.

Measurements were performed on a series of vinyl acetate based paint samples, each with a different concentration of stainless steel flake. The material's complex refractive index, n – i k, was shown to be well behaved as a function of the metal flake loading ratio, ρ. An algorithm was developed to describe the behavior analytically and expressed as:

$$n \approx 1.73 \times 10^{(0.0201\,\rho)} \qquad \text{and} \qquad k \approx 0.082 \times 10^{(0.0504\,\rho)} \qquad (1)$$

for a loading ratio in the regime of $0 \leq \rho \leq 30$ grams of stainless steel flake per liter of vinyl acetate binder.

The technique of characterizing and tailoring the dielectric constant of metal loaded paints at terahertz frequencies had been previously demonstrated at ULRF.[2] When tied to theoretical modeling of the paint's reflectivity as a function of thickness, dielectric constant and frequency using the Fresnel equations, anechoic coatings can be designed to provide more than –25dB of radar cross section (RCS) reduction at any frequency in the terahertz regime.

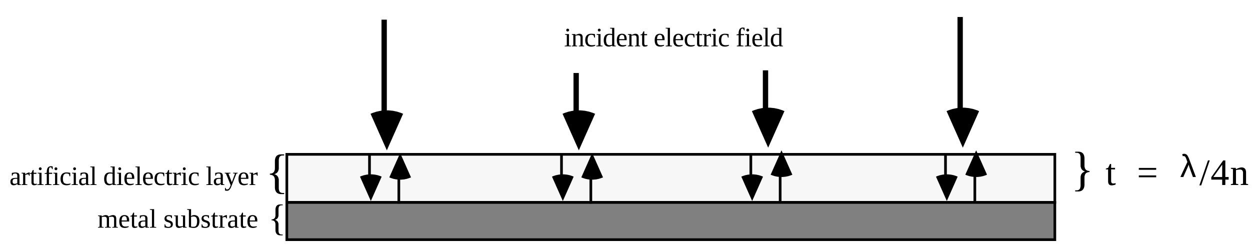

Figure 1. The FIRAM depicted is a resonant absorption structure which consists of a quarter wavelength thick homogeneous lossy dielectric surface on a metal plate.

3. THEORY OF THE RESONANT ABSORBER

The dielectric properties of metallic paints at terahertz frequencies are ideal for providing an anechoic layer on metal surfaces. As shown in figure 1, these paints provide the vehicle for which phase and amplitude matching of the incident electric field can occur. The paint's complex refractive index model, defined by equations 1, allows calculation of the FIRAM's optical behavior using the Fresnel equations.[3] With a reflectivity of ≈ 1 for aluminum[4], the resonant structure's theoretical reflectivity was approximated as

$$R \approx \left| \frac{r + e^{-2 i \beta}}{1 + r e^{-2 i \beta}} \right|^2 \tag{2}$$

where $$r = \frac{N - 1}{N + 1}$$ and $$\beta = (2\pi N t) / \lambda$$

are the paint's front surface reflectivity and phase thickness, respectively.

Close inspection of equation 2 indicates that a dielectric layer with phase thickness equal to a quarter wavelength should cause destructive interference at the material's front surface. Furthermore, if the amplitude of electric field reflected from the paint's front surface equals that of the back surface which suffers absorption, all of the incident electric field is reflected back into the material and complete resonant absorption, i.e. the FIRAM, is established.

4. EXPERIMENTAL MEASUREMENTS

Calculations were performed to predict fabrication parameters for a range of FIRAM samples using the paint's experimentally determined dielectric properties along with the theory described. The far-infrared reflectivity of these samples were measured over a frequency regime of 300 GHz to 3 THz using fourier transform spectroscopy (FTS). Due to uncertainties in the refractive index model (Equation 1), the predicted fabrication parameters were only adequate for evaluating the FIRAM's general reflectivity behavior. Therefore several samples of metallic paint were prepared and tested with stainless steel loading ratios ranging from 15 to 25 grams of stainless steel flake per liter of vinyl acetate binder. Also each paint sample was applied to several aluminum substrates for thicknesses which varied from 0.0005" to 0.005".

The frequency at which reflectivity nulls occurred were identified for each sample and the FTS measurement results were compared to theory. Careful analysis of the resonant structure's multiple reflection theory (Equation 2), allowed modification of the paint's refractive index model to achieve tighter characterization tolerances at the frequency of interest (0.585 THz). From the modified model, the artificial dielectric layer was specifically matched in metal loading and thickness to create a Dällenbach layer which produced an RCS reduction of –27dB at 0.585 THz. Reflectivity data on additional samples will be presented to indicate the flexibility of fabricating FIRAMs at other frequencies in the terahertz regime.

5. CONCLUSIONS

We have demonstrated that artificial dielectric layers, in the form of metallic paints, can be optimized to operate as resonant absorbers for any frequency over the regime of 300 GHz to 3 THz. We also have determined that these anechoic coatings can be designed to provide more than –25dB of radar cross section (RCS) reduction. Since the base paints are relatively inexpensive and easily applied using a standard spray gun, the technology is well suited for large scale operations requiring FIRAM at terahertz radar frequencies.

6. ACKNOWLEDGEMENTS

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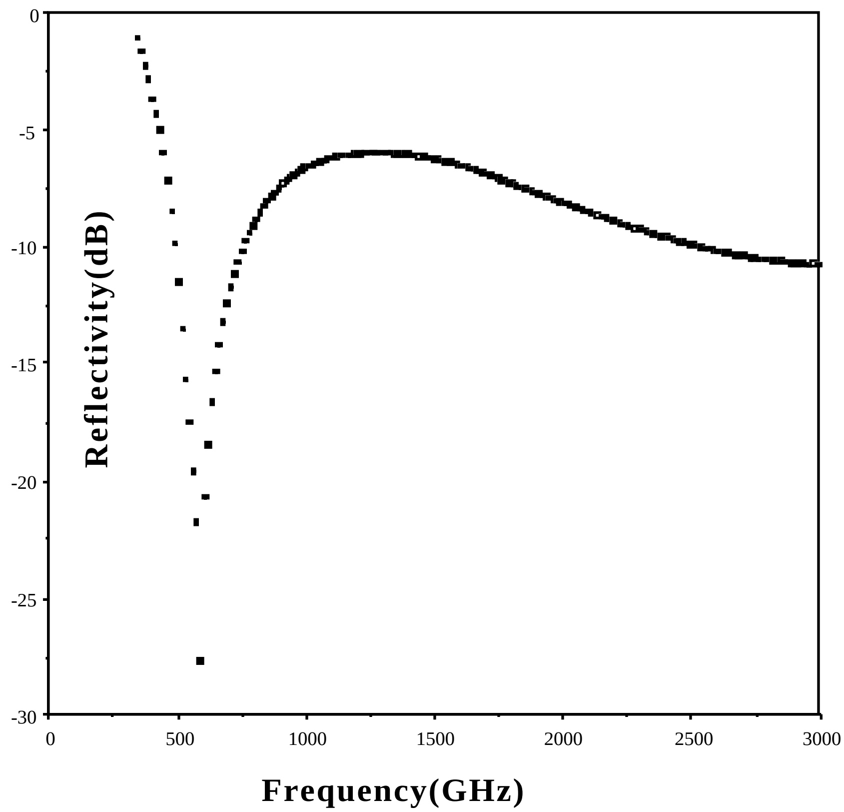

Figure 2. The reflectivity as a function of frequency for an artificial dielectric material specifically matched in metal loading and thickness to provide an RCS reduction of –27dB at 0.585 terahertz.

6. REFERENCES

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