Non-Destructive Evaluation of Low Observable Coating Degradation Using Terahertz Time-Domain Spectroscopy

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Abstract

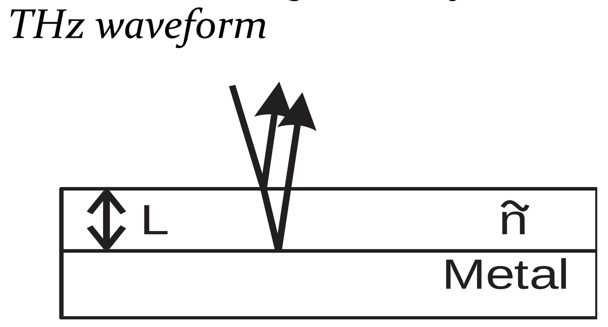
Terahertz Time Domain (THz-TD) reflection spectroscopy is utilized as a non-destructive test evaluation method to assess the degradation of Low Observable (LO) coatings. Accelerated aging techniques including temperature, UV light exposure and humidity, were performed continuously on multilayer paint samples. The exposed samples were measured using established testing methods as well as THz-TD techniques at various points throughout the degradation. Using an effective medium model for terahertz propagation in a paint sample combined with a non-linear least squares fitting method, the refractive index was extracted. Established materials characterization techniques suggest degradation begins with pitting of the top coat layer followed by catalytic degradation of rain erosion polymer. THz-TD measures show an increase in the magnitude of the imaginary refractive index with degradation.

Relevance

Low Observable (LO) platforms have required significantly more maintenance than conventional aircraft. The maintenance results in a 14 month period to strip and recoat B2 aircraft every seven years, for example. Compared to conventional aircraft coatings, the removal and reapplication of LO coatings require large quantities of Hazardous Air Pollutants and Volatile Organic Compounds thereby generating a significant hazardous waste stream in the process: roughly 80,000 lbs of hazardous waste per aircraft, along with 400 gallons of chemical stripper. The frequency and extent of such depot maintenance could be reduced with accurate knowledge of LO coating durability.

Methods

- Two measurements required for analysis:
  - *Reference THz waveform*
  - *Sample THz waveform*
- $r(v) = |E_s(v)|/|E_r(v)|$
  - *v is the THz frequency*
  - *s and r denote sample and reference respectively*
  - *$|E(v)|$ denotes the magnitude of the Fourier transform of the THz waveform*

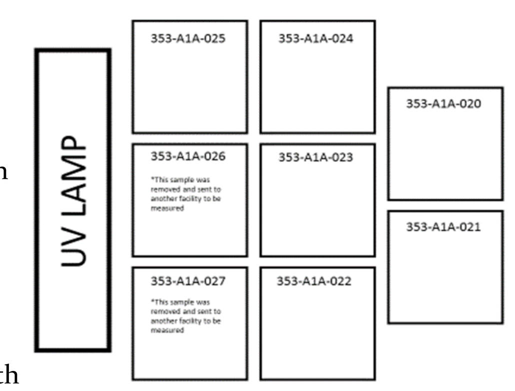


Methods

- $r(v,\tilde{n}) = -\dfrac{e^{-\frac{i\tilde{n}2\pi vL}{c}}(\tilde{n}+1)+e^{\frac{i\tilde{n}2\pi vL}{c}}(\tilde{n}-1)}{e^{\frac{i\tilde{n}2\pi vL}{c}}(\tilde{n}+1)+e^{-\frac{i\tilde{n}2\pi vL}{c}}(\tilde{n}-1)}$
  - *$\tilde{n} = n_r + in_i$ is the complex refractive index comprised of the real and imaginary part*
  - *v is the THz frequency*
  - *c is the speed of light*
  - *L is the total thickness of the paint layer*

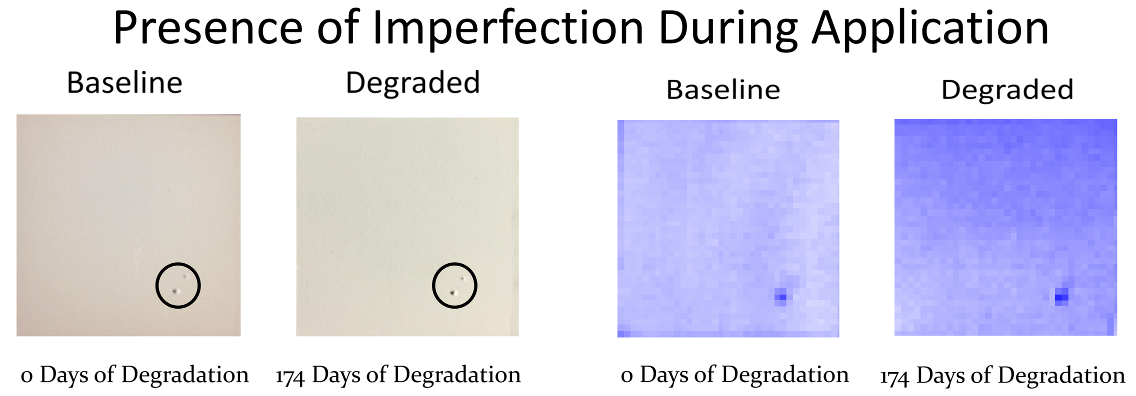
Degradation Protocol

- Method #1:
  - *Degradation Conditions:*
    - Humidity – 95%
    - UV light (8 watts) - 254 nm wavelength
- Method #2:
  - *Degradation Conditions:*
    - Humidity – Room dependent
    - UV light (25 watts) - 254 nm wavelength
    - 0.5 molar NaCl solution in water



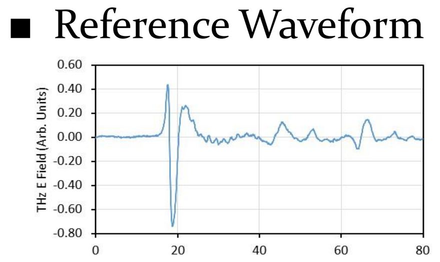
Results

Presence of Imperfection During Application

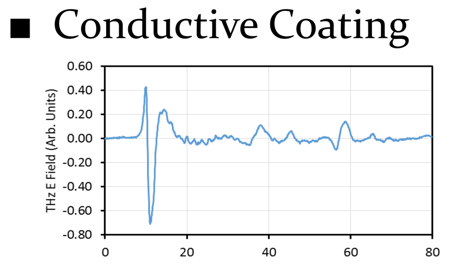


Baseline – Single Paint Layers

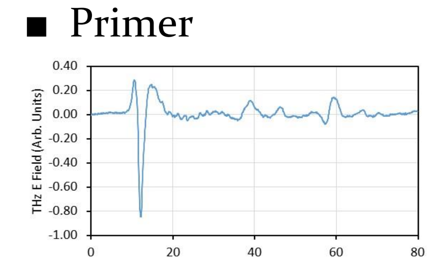
- Reference Waveform



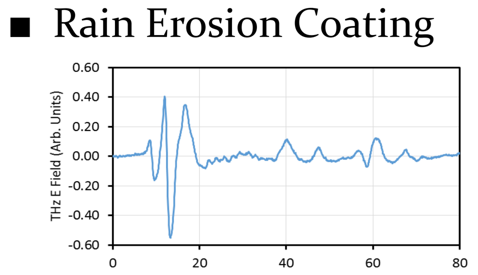
- Conductive Coating



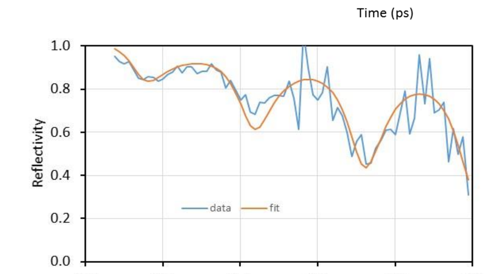
- Primer



- Rain Erosion Coating



- Best Fit
  - *Rain Erosion Coating*



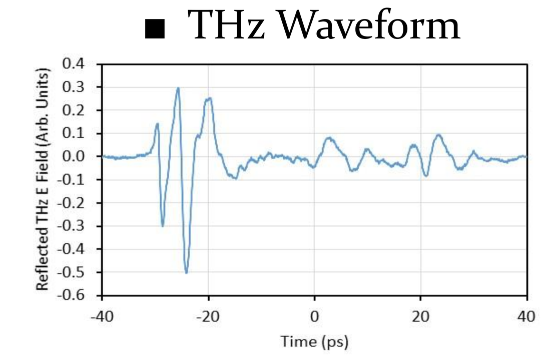
- Extracted THz Refractive Indices for all Layers

Layer	Real Refractive Index	Imaginary Refractive Index
Primer	1.67	-1.22 x 10⁻²
Rain Erosion	2.00	-5.23 x 10⁻²
Topcoat	1.91	-2.30 x 10⁻²

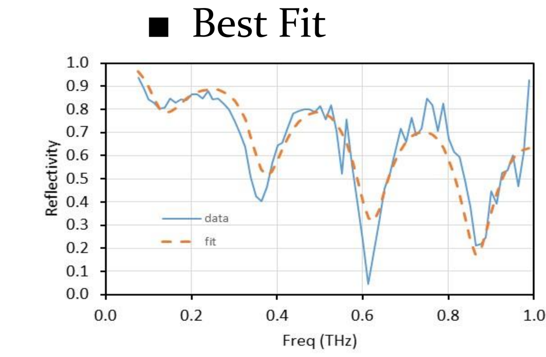
Results

Undegraded Multilayer Stack

- THz Waveform



- Best Fit



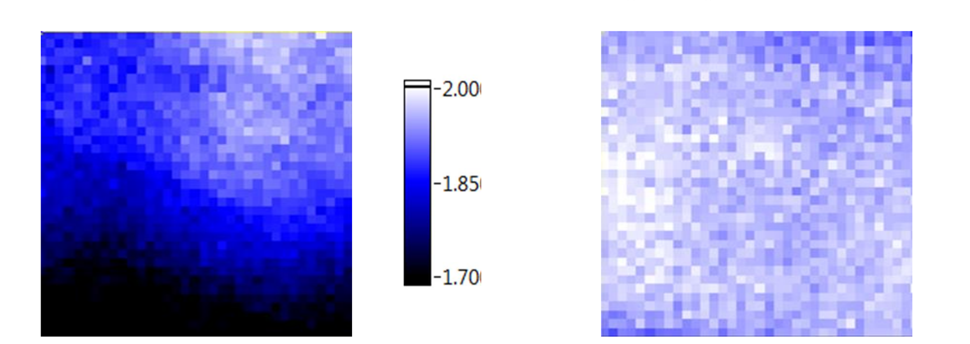
- Effective refractive index extracted from the best fit: $\tilde{n} = 1.88 - i6.79 \times 10^{-2}$

THz Imaging

- Sample 353-A1A-025

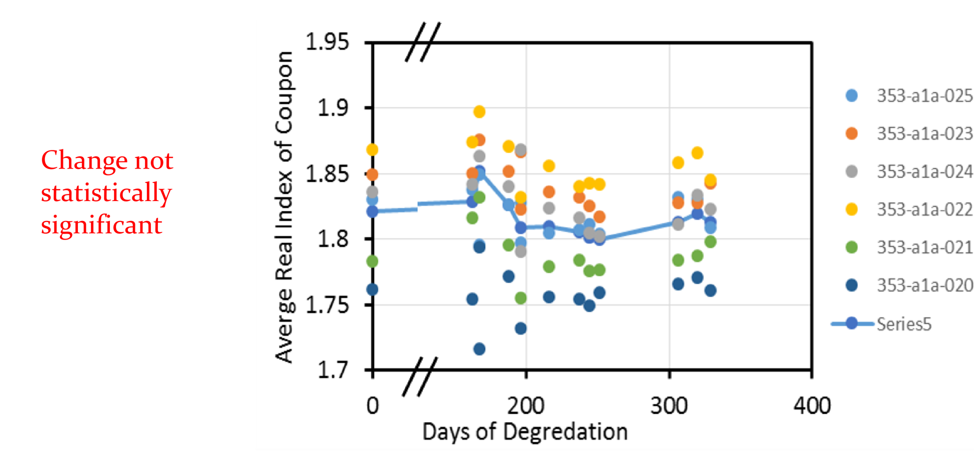
Real Refractive Index

Imaginary Refractive Index



THz Property Changes – Degraded Samples

- Real Refractive Index



- Imaginary Refractive Index

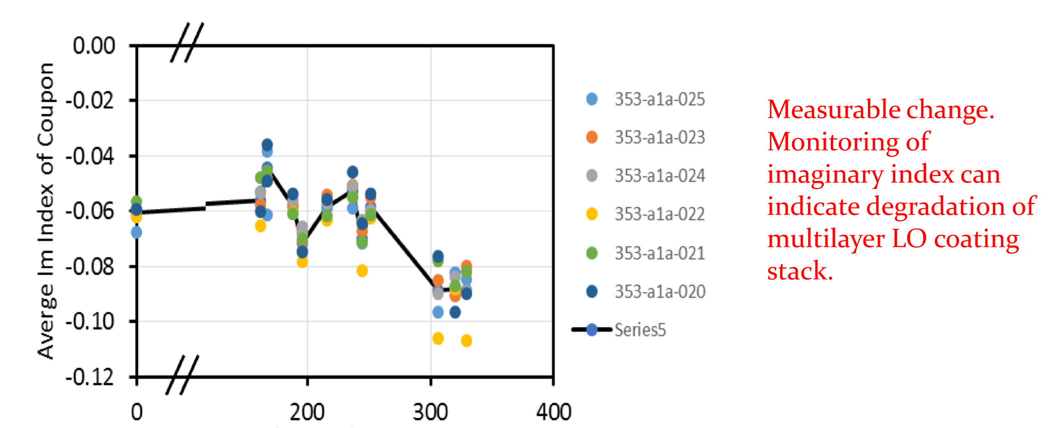
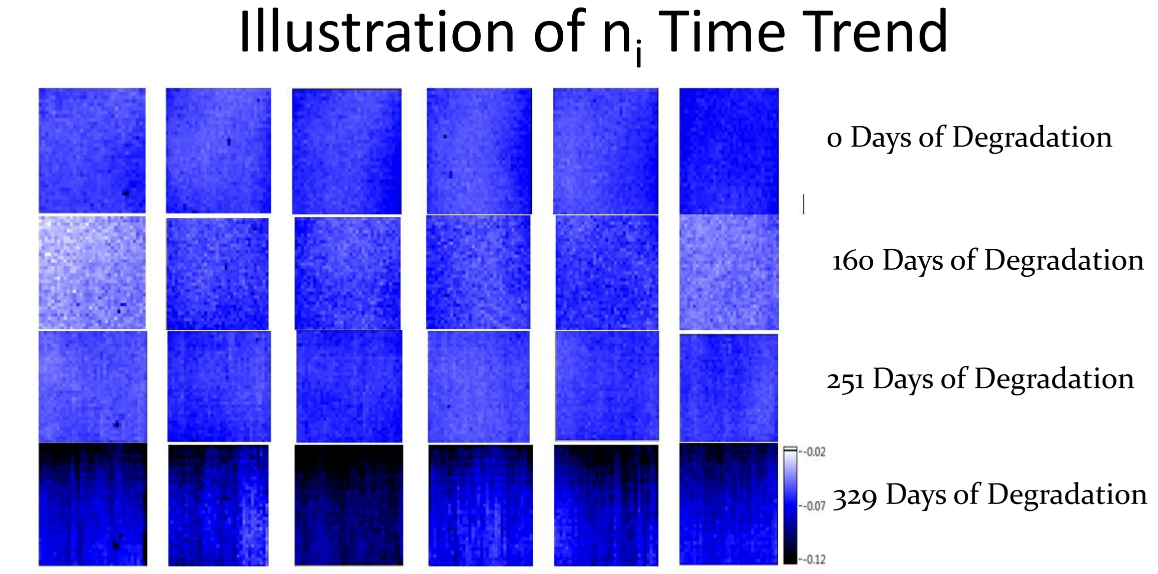
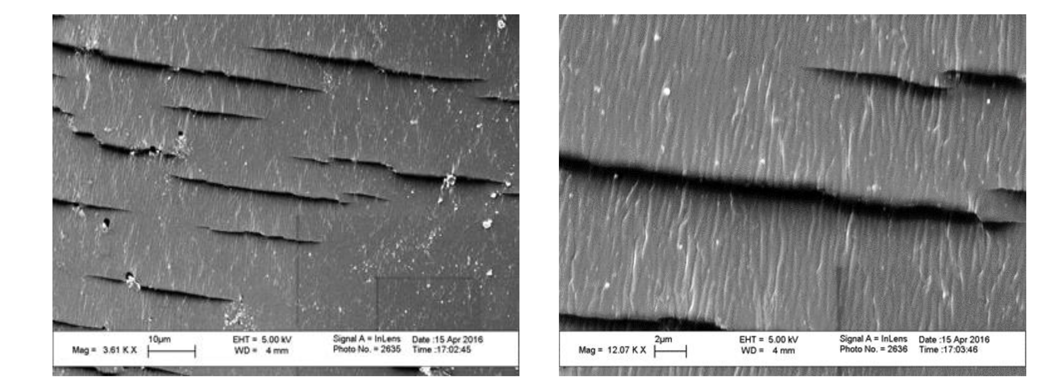


Illustration of n_i Time Trend

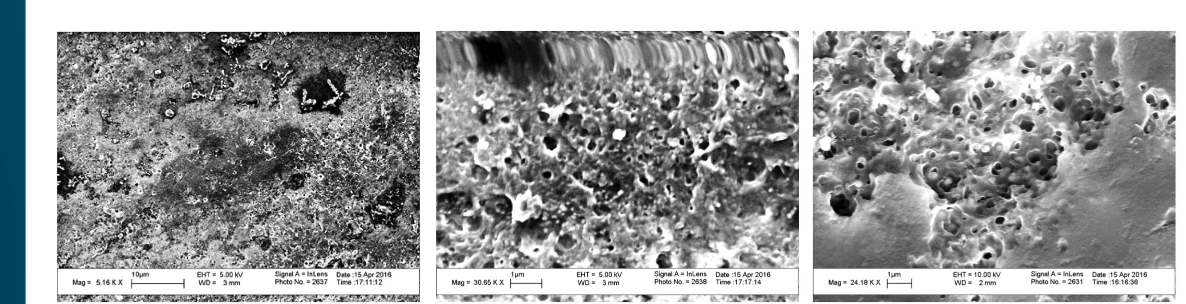


Degradation Mechanism

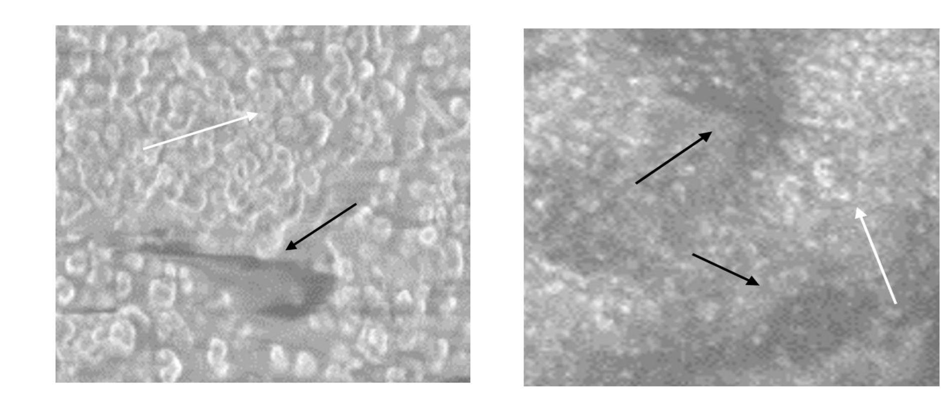
- Pristine multilayer stack coated with platinum



- NaCl solution in water with UV illumination degraded multilayer stack



- Humidity and UV degraded multilayer stack



- Begins in the top coat layer
- 254 nm UV illumination in combination with the presence of moisture works partially with oxides ZnO and TiO_2 as catalysts to decompose the top coat polymer
  - *creating porosity in the top coat layer.*
- As the topcoat layer becomes more porous, it allows water vapor to permeate the topcoat layer and interact with the rain erosion layer.
- The presence of the salt accelerates the pitting degradation.

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