
DURIP FA 9550– 11–1–0316

**Laboratory of excellence for
characterization of electromagnetic
properties of
nanocomposite materials**

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AFOSR DURIP FA9550-11-1-0316: Laboratory of Excellence for Characterization of Electromagnetic Properties of Nanocomposite Materials

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Thermodynamic properties

MicroMag 2900 AGM System

- Analysis of magnetic hysteresis for different types of nanomaterials (solid particles, powders, ultra thin films);
- Wide range of temperatures, 10°K -473°K

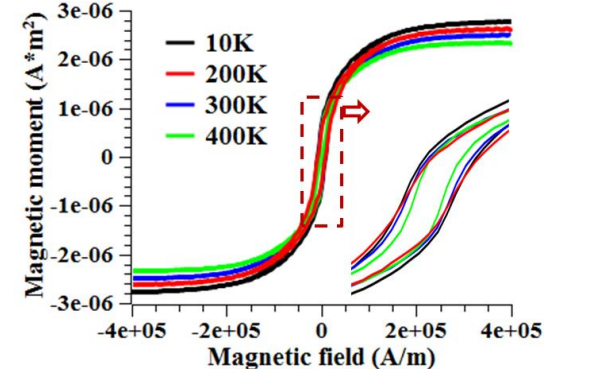
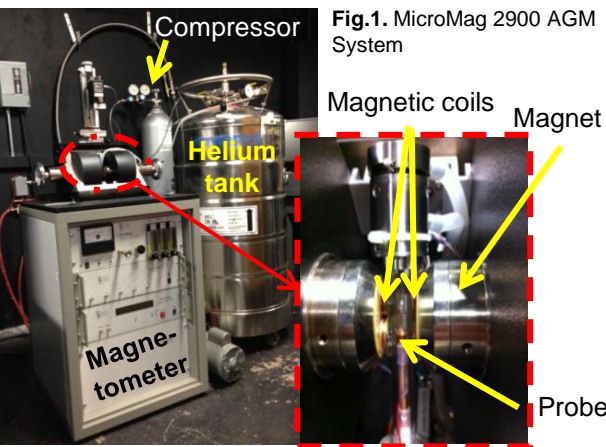


Fig.2. Hysteresis loops of nickel nanorods in aluminum membrane at different temperatures
Publication: Probing viscosity of nanoliter droplets of butterfly saliva by magnetic rotational spectroscopy, *Applied Physics Letters*, 102 (2013)

Kinetic properties (GHz)

Digital Serial Analyzer 8300

- high-performance True-Differential TDR Measurements;
- impedance characterization;
- measurement-based SPICE modeling

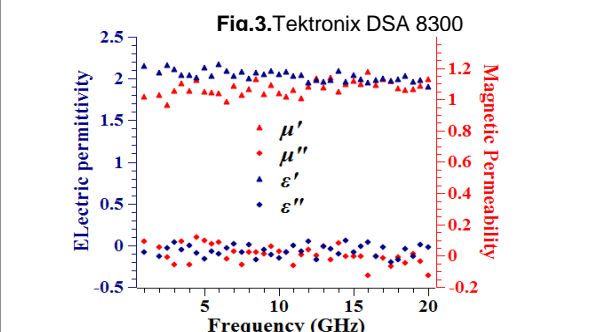


Fig.4. Permeability and permittivity of 0.3% dispersion of cobalt nanoparticles in paraffin measured by TDR

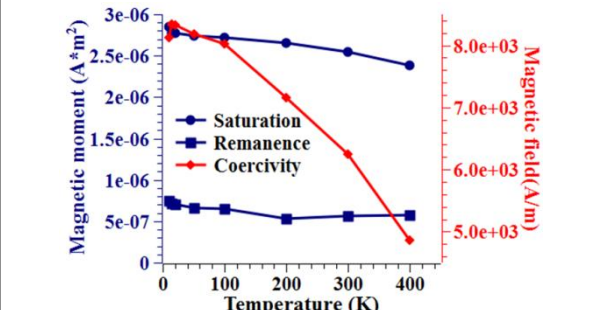


Fig.5. Temperature dependent magnetic properties

Kinetic properties (optical frequencies)

Spectroscopic Ellipsometer PHE 102

- fast determination of thickness and refractive index of single or multi-layer samples;
- spectral dependence of refractive index, dielectric constants and other properties of materials ;
- wide spectral range 250-1100 nm;
- variable angle from 20° to 90° with 5° step;
- large samples up to 150 mm;
- extensive library of materials' properties.



Fig.6. The PHE-102 is a variable angle spectroscopic ellipsometer

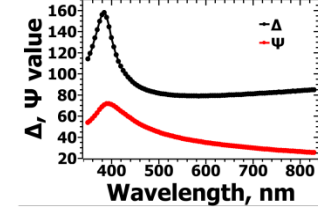


Fig.7. Experimental data collected on 80 nm thick polystyrene film.

Q-Sense E1 quartz microbalance

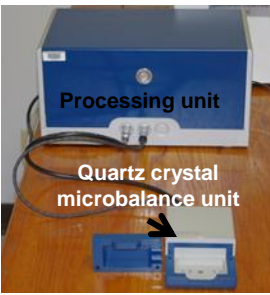


Fig.8. Q-Sense E1 is a reliable, single-sensor quartz crystal microbalance with dissipation monitoring

- interfacial properties in terms of structure and mass with nan gram sensitivity;
- insight on viscoelastic properties of many surface substrates;
- measurements in a flow;
- simultaneous mass and ellipsometry measurements;
- real-time results monitoring.

MOTIVATION:

Full analysis of the materials response to EM radiation requires knowledge of thermodynamic properties of magnetic materials, i.e. a hysteresis loop and its temperature dependence; it also requires an analysis of kinetic properties of materials in a wide frequency band.

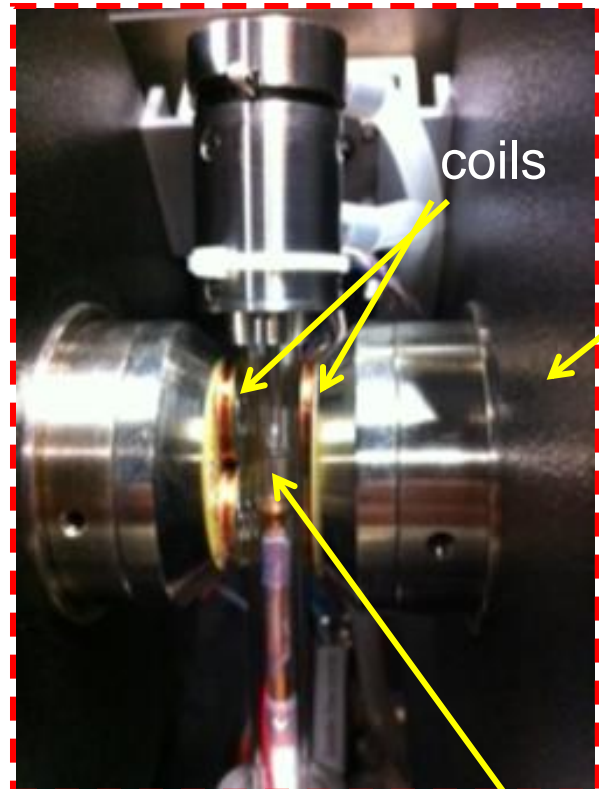
The acquired system consists of

- alternative gradient magnetometer,**
- time domain reflectometer,**
- spectroscopic ellipsometer.**

These instruments have overlapping capabilities to study the frequency dependence of dielectric permittivity and magnetic permeability of nanocomposites at the microwave and optical wavelengths, hysteresis loops of magnetic nanocomposites, and the nanoparticle ordering, distribution, and film morphology.

Compressor

Helium
tank



Magnet

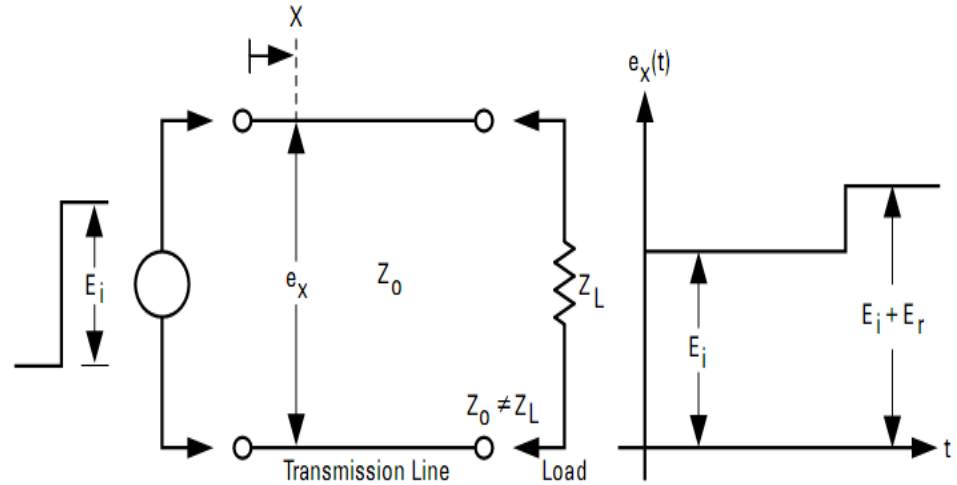
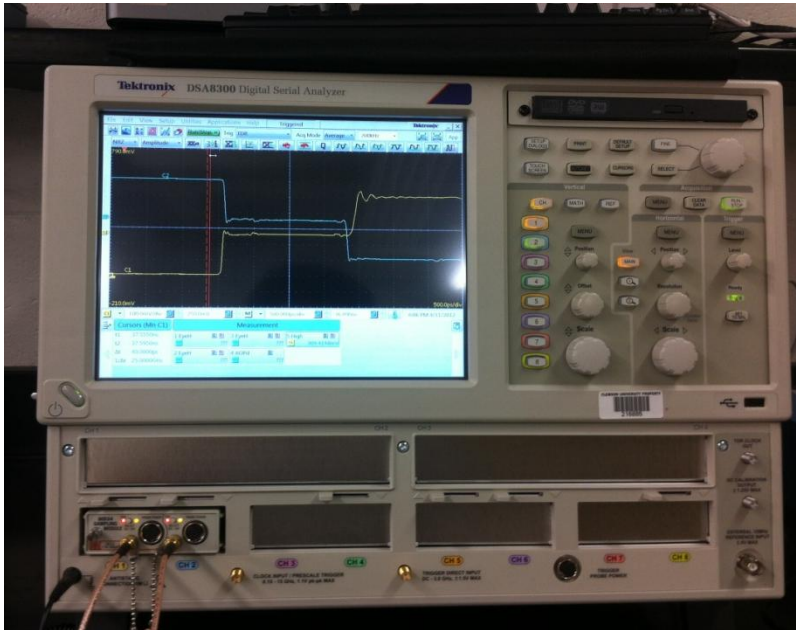
Probe

Time Domain Reflectometer (TDR)

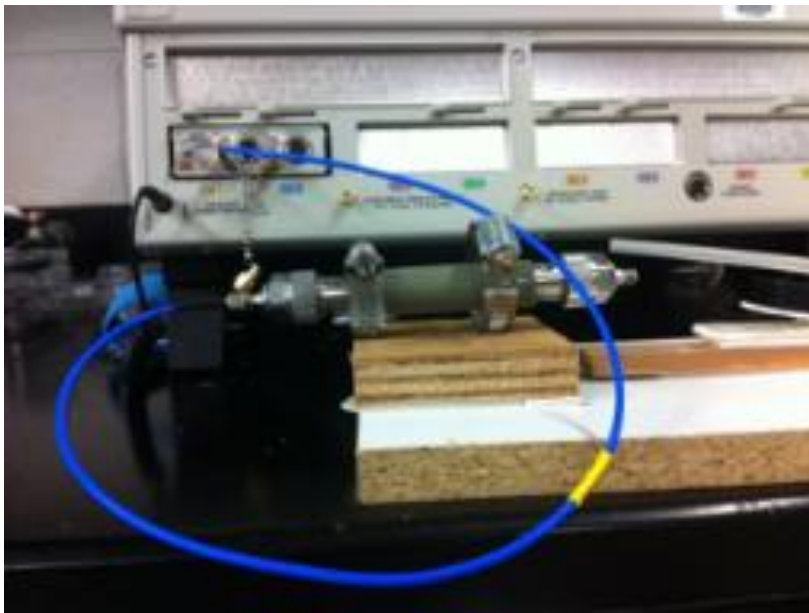
- **TDR measures allows one to measure the signal directly in the time domain. Then the Fourier transform is applied to transform the signal to the frequency domain \Rightarrow**
- **the permittivity and permeability as functions of frequency**

The TDR system

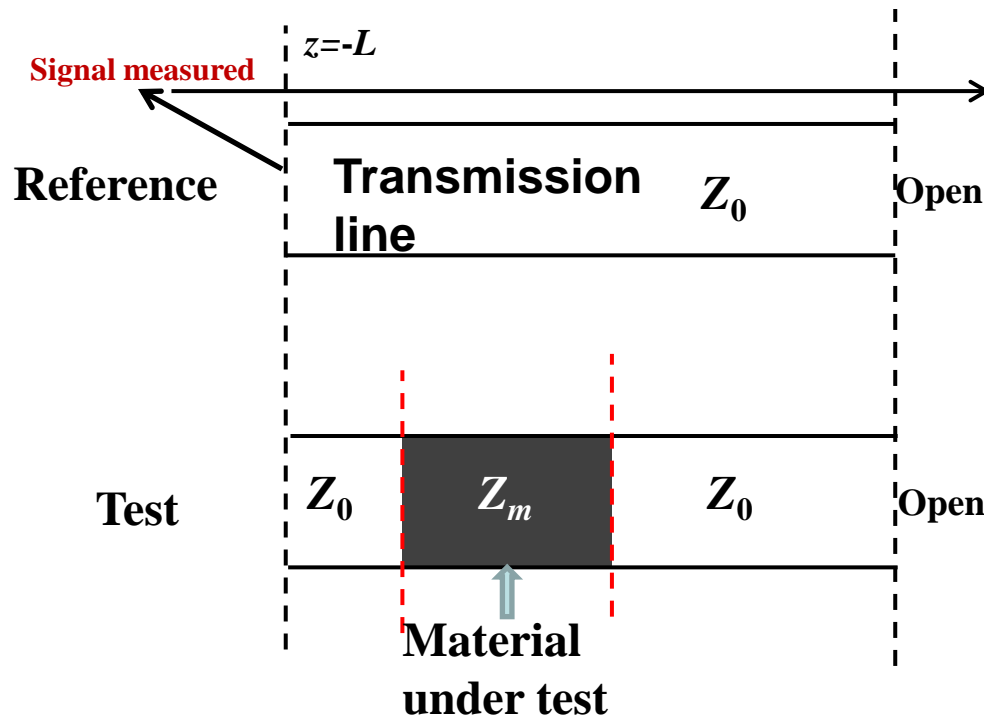
Schematic of signal propagation in TDR



TDR first generates a step voltage (E_i), which is travelling through the transmission line. After meeting some mismatch load shown in the schematic, some part of the signal is reflected and travels backward (E_r). By comparing E_r and E_i we can obtain the properties of the load. The time that the pulse E_r takes to travel back to the source gives us the position of the mismatch load.



Modeling



Transmission line is open ended. (Load at the end is infinity)

Material under test is inserted into the transmission line.

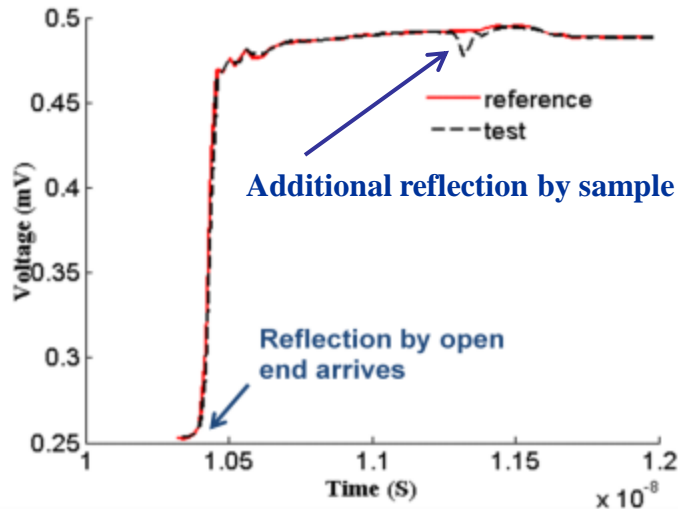
Z_0 : characteristic impedance of transmission line

Z_m : impedance of the part filled with the material

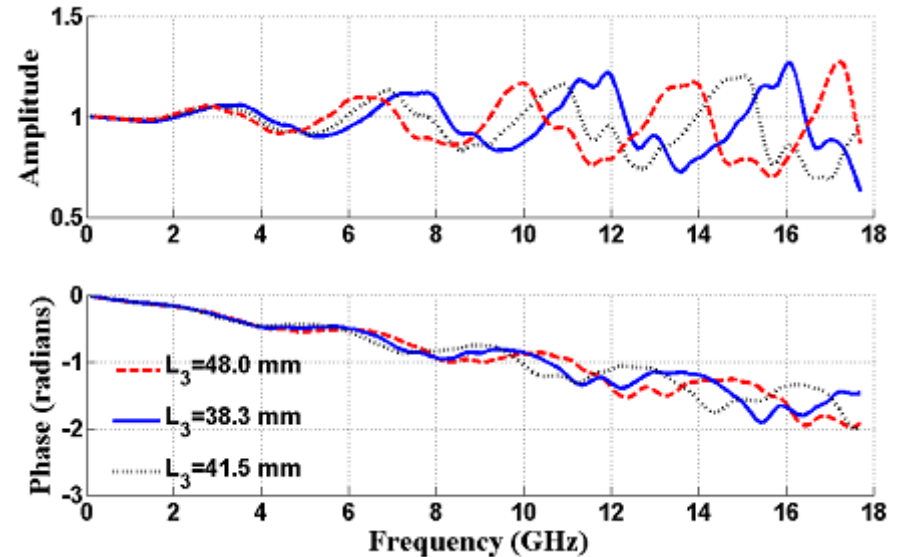
Two groups of experiments are performed. One is the reference experiment allowing the researcher to calibrate the signal with the empty wave guide. The other is an actual test. The reflection signal is measured for both cases. The difference in these two reflection signals is used to analyze the property of the material.

Signal processing in TDR

Time domain



Frequency domain S parameter

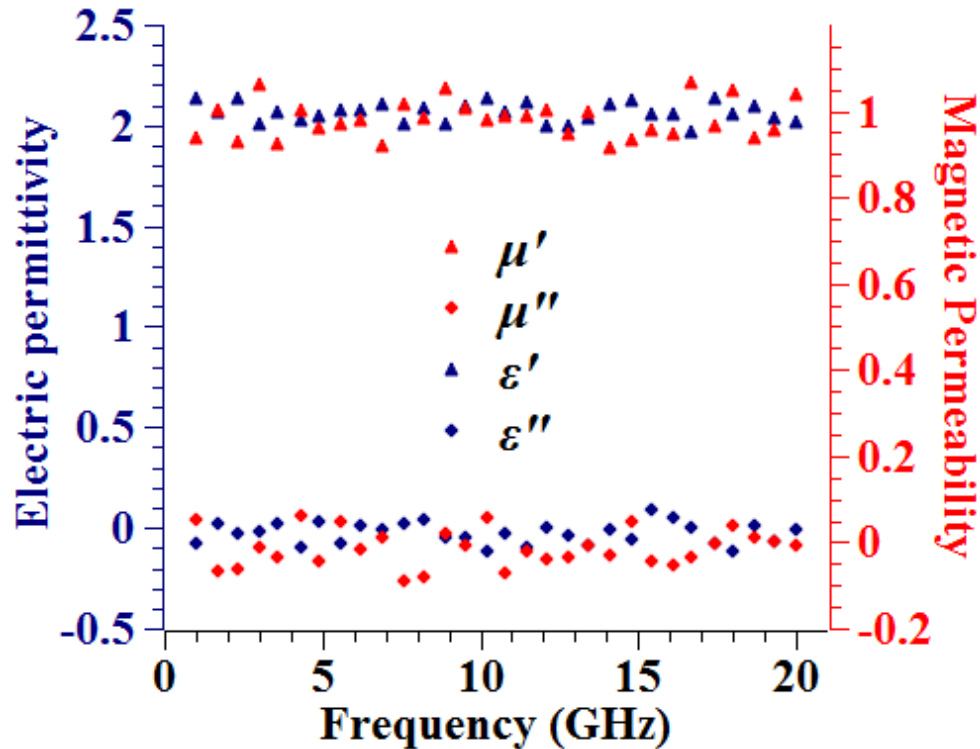


Signal is measured in the time domain and then its Fourier transform is taken to convert it into the frequency domain. The S parameter is defined as:

$$S(\omega) = R(\omega) / V(\omega)$$

where $R(\omega)$ is the reflected signal and $V(\omega)$ is the incident signal. The right graph actually shows $S_{\text{test}} / S_{\text{ref}}$. The S-parameter is generally a complex number reproduced as $S = A \exp(i\phi)$.

Calibration with paraffin



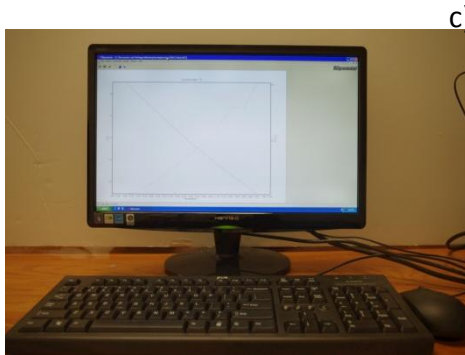
Permeability and permittivity of paraffin

$$\epsilon = \epsilon' - i\epsilon'' \quad , \quad \mu = \mu' - i\mu''$$

Paraffin is lossless in the GHz range

Spectroscopic Ellipsometer PHE -102

PHE-102 is a variable angle spectroscopic ellipsometer



Capabilities:

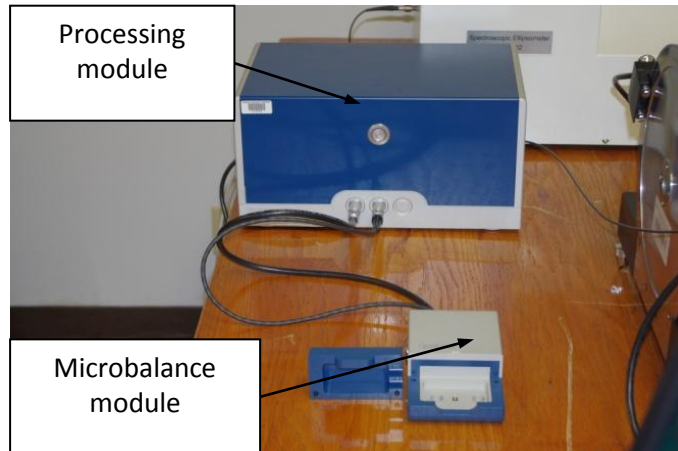
- fast determination of thickness and refractive index of single or multi-layer samples;
- spectral dependence of refractive index, dielectric constants and other properties of materials ;
- wide spectral range 250-1100 nm;
- variable angle from 20° to 90° with 5° step;
- large samples up to 150 mm;
- extensive library of materials' properties.

Experimental set-up of the PHE-102 spectroscopic ellipsometer:

*a) ellipsometer; b) spectrometer; c) computer with the software ;
d) ozone exhaust system.*

Q-Sense E1 quartz microbalance

E1 is a single-sensor quartz crystal microbalance with dissipation monitoring



a)



b)



c)



d)



e)

Components of E1 quartz microbalance system: a) microbalance and processing units, b) peristaltic pump c) flow module, d) ellipsometry module and e) the set of sensors

Q-Sense E1 quartz microbalance

Application:

- characterization of interface properties in terms of structure and mass with nanogram sensitivity;
- insight on viscoelastic properties of many surface substrates

Capabilities:

- sensitivity (0.5 ng/cm²);
- insight on viscoelastic properties of many surface substrates;
- measurements in a flow (0-1 ml/min with the supplied peristaltic pump);
- simultaneous mass and ellipsometry measurements;
- high temperature measurements (up to 45 °C);
- real-time results monitoring with high time resolution (200 points per second)

Current state:

- the microbalance undergoes series of initial tests to ensure its proper operation