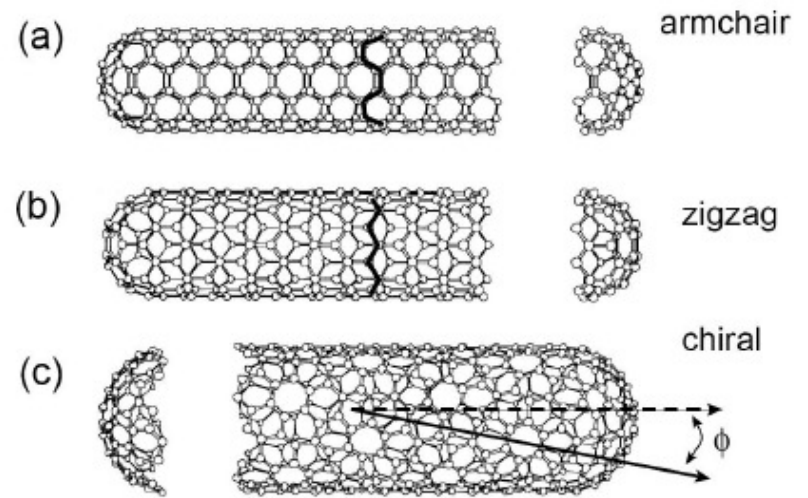


Electromagnetic Applications
in
Nanotechnology

Carbon nanotubes (CNTs)

- ❑ **Hexagonal networks of carbon atoms**
 - 1nm diameter
 - 1 to 100 microns of length
- ❑ **Layer of graphite rolled up into a cylinder**
- ❑ **Manufactured:**
 - Carbon arc-discharge technique
 - Laser-ablation technique
 - Chemical vapor decomposition technique (CVD)
- ❑ **Dielectric properties controlled through:**
 - Tube diameter
 - Chirality
 - Doping



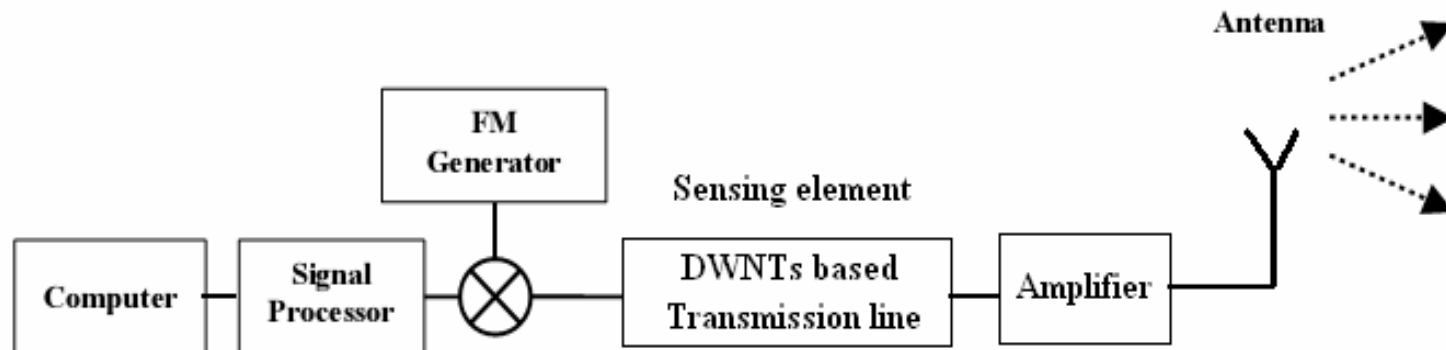
- Single Wall Nanotube – 1 Wall
- Double Wall Nanotube – 2 Walls
- Multi-Wall Nanotube ~ 50 Walls

CNT Mixtures/Composites Properties

- ❑ Different mixtures of CNTs (Ceramic/SWNT, Epoxy/SWNT, Epoxy/MWNT, etc.)
 - => conductivity ranging from 10^{-3} to 10^2
- ❑ Control weight % of CNTs in the composites
 - => dielectric constant in the range of 1-16 around 1-20GHz range
- ❑ Adsorption of different gases cause different changes in:
 - Dielectric constant
 - Loss tangent
- ❑ Functionalized CNTs in composites to improve gas sensitivity
- ❑ Vertically alignment of CNTs in composites to improve gas sensitivity
- ❑ **Quick response time** (smaller than contemporary sensors)
- ❑ **Ultra-high sensitivity** (order of part-per-billion and part-per-million)
- ❑ System is reversible, however long recovery time

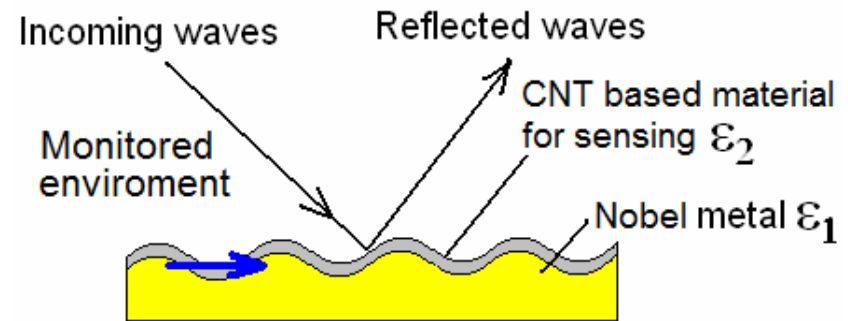
CNT based Transmission line for Gas sensing

- ❑ The substrate is a CNT based materials that are sensitive to gases such as NO_x, Nitrogen, Carbon dioxide, etc.
- ❑ When in contact with intruding gases, the dielectric constant and conductivity of the CNT material are altered.
- ❑ A co-planar transmission line with CNT based substrate was known to produce magnitude and phase changes in the transmitted signal when in contact with the intruding gases.
- ❑ The CNT transmission line is utilized with our designed antenna and system in Figure 1 to produce observable parameters for easy detection in wireless gas sensing.



Surface Plasmon Applications

- ❑ Using Surface Plasmon Resonance (SPR) to detect changes in electrical properties of CNT based material thin films
 - => integrating with standard wireless network
- ❑ Grating structure to couple waves in microwave range frequencies
- ❑ The shift in frequency (hundred of MHz in the operating range of 60 GHz) and changes in magnitude of the reflected waves allows accurate remote gas sensing.
- ❑ Our designed sensor is completely passive and capable of selective sensing.

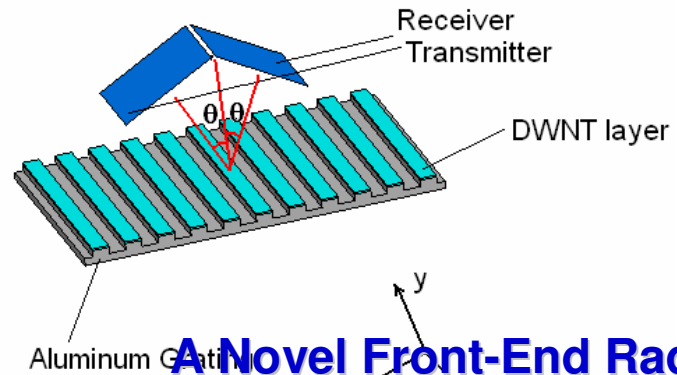


$$k_{spr} = \frac{\omega}{c} \sqrt{\frac{\epsilon_1 \cdot \epsilon_2}{\epsilon_1 + \epsilon_2}}$$

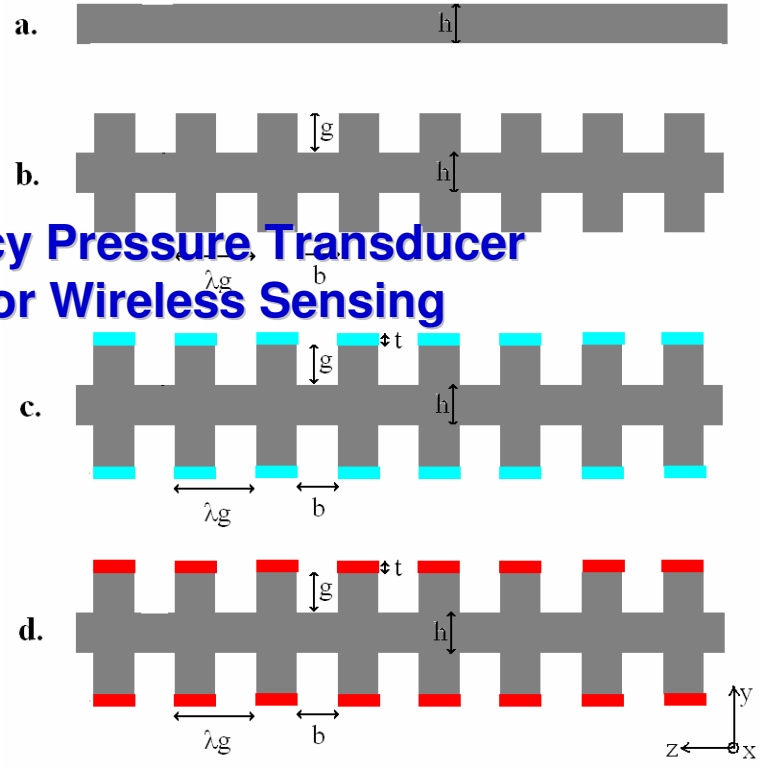
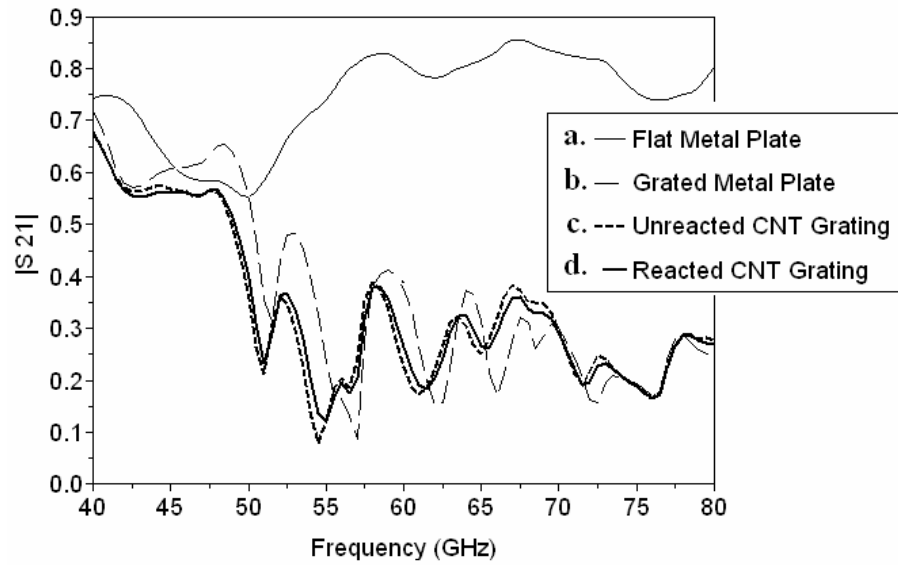
$$k_{spr} = \frac{\omega}{c} \sqrt{\epsilon_{CNT}}$$

$$k_x = \frac{\omega}{c} \cdot \sin(\theta) + \frac{2\pi n}{\lambda_g}$$

CNT based Gas Sensing using Surface Plasmons



A Novel Front-End Radio Frequency Pressure Transducer based on a Dual-band Resonator for Wireless Sensing



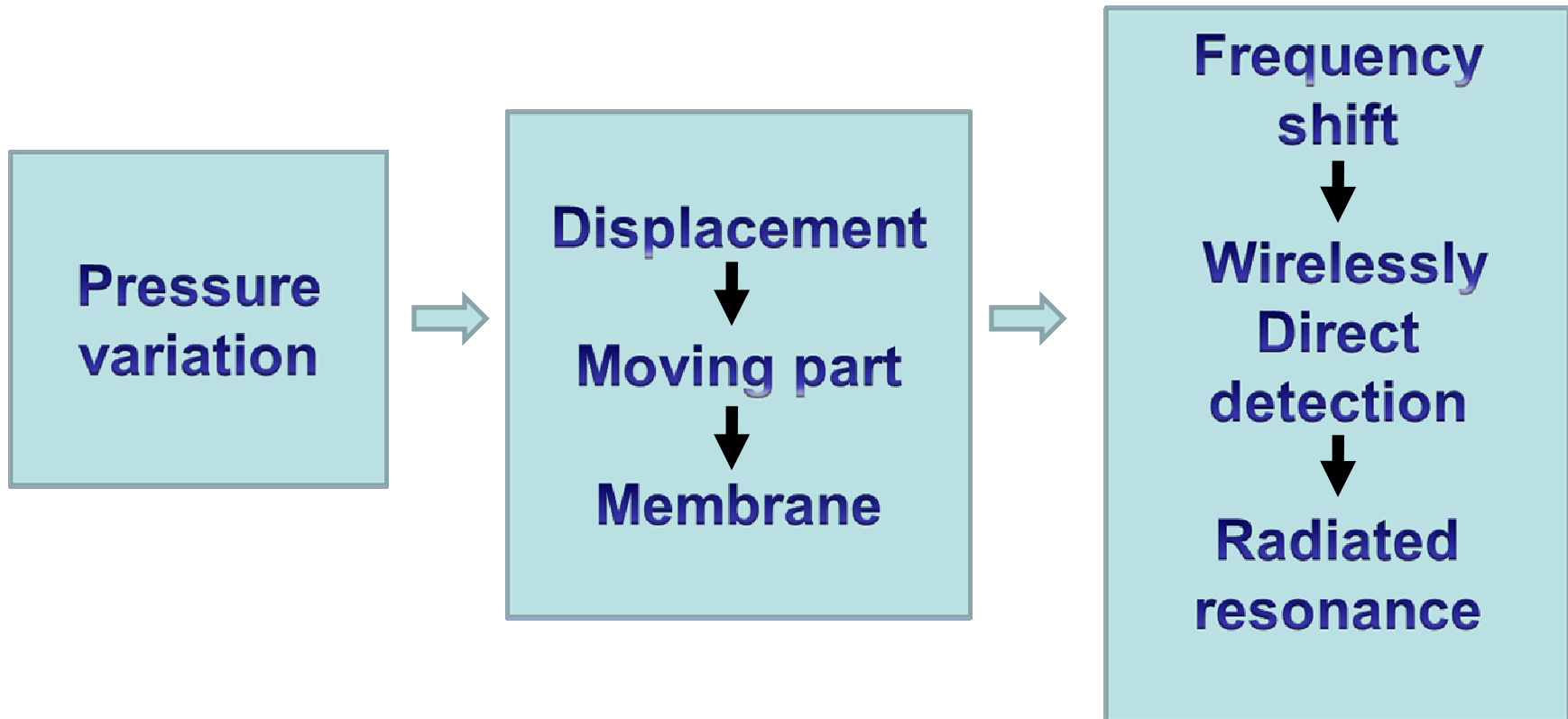
A Novel Front-End Radio Frequency Pressure Transducer based on a Dual-band Resonator for Wireless Sensing

Team: Trang Thai, Gerald DeJean

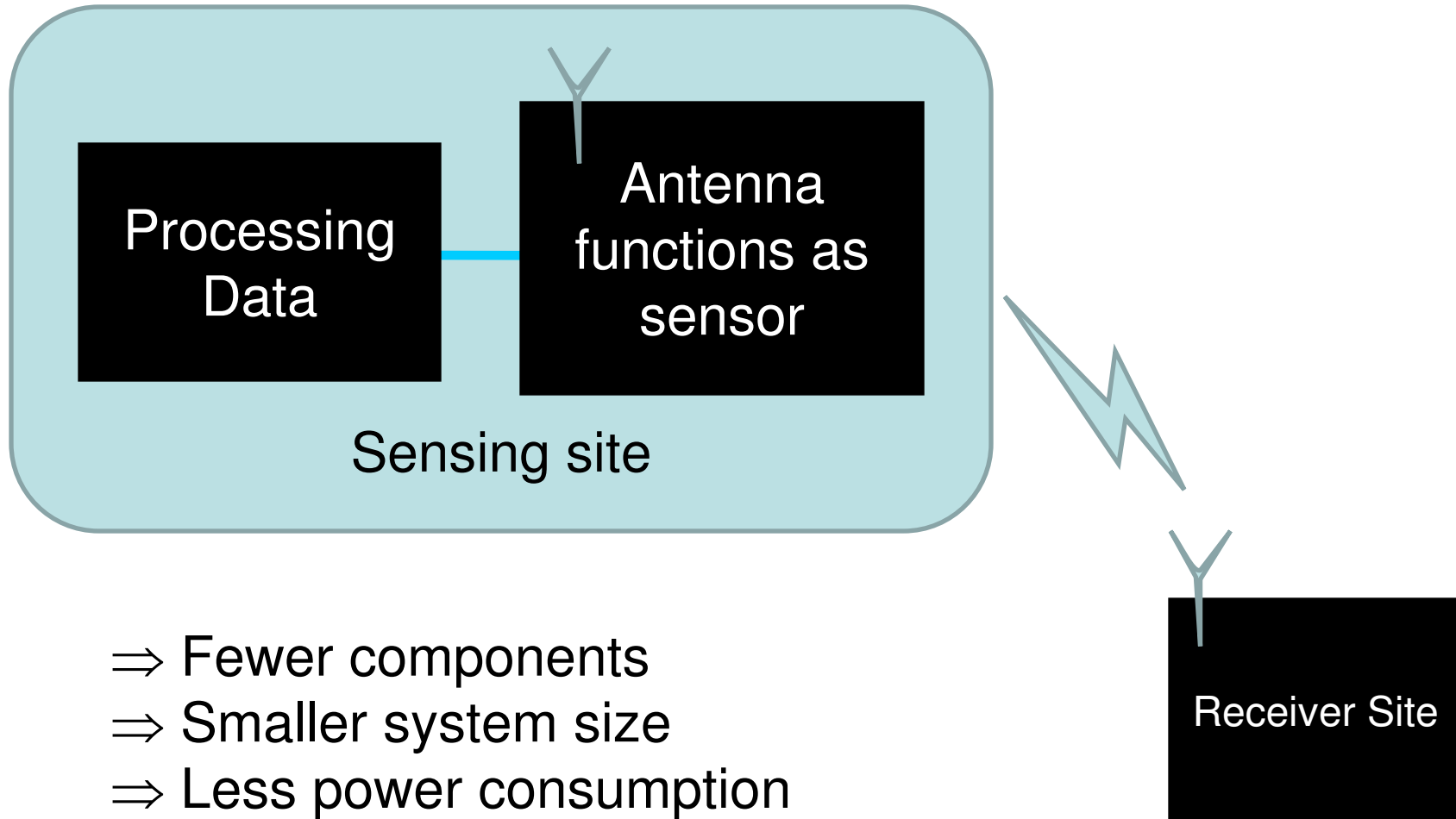
Pressure Sensor Applications

- ❑ Automation: measuring full/empty tank of liquid, leakage monitoring, etc
- ❑ Process control:
- ❑ Electronics: microphones
- ❑ Automotive: engine condition, airbag, acceleration monitoring, tire pressure, etc
- ❑ Medical: blood, artery, intracranial pressure monitoring, hearing aid equipments, etc.
- ❑ Public safety: weather, food processing, use together with gas sensors

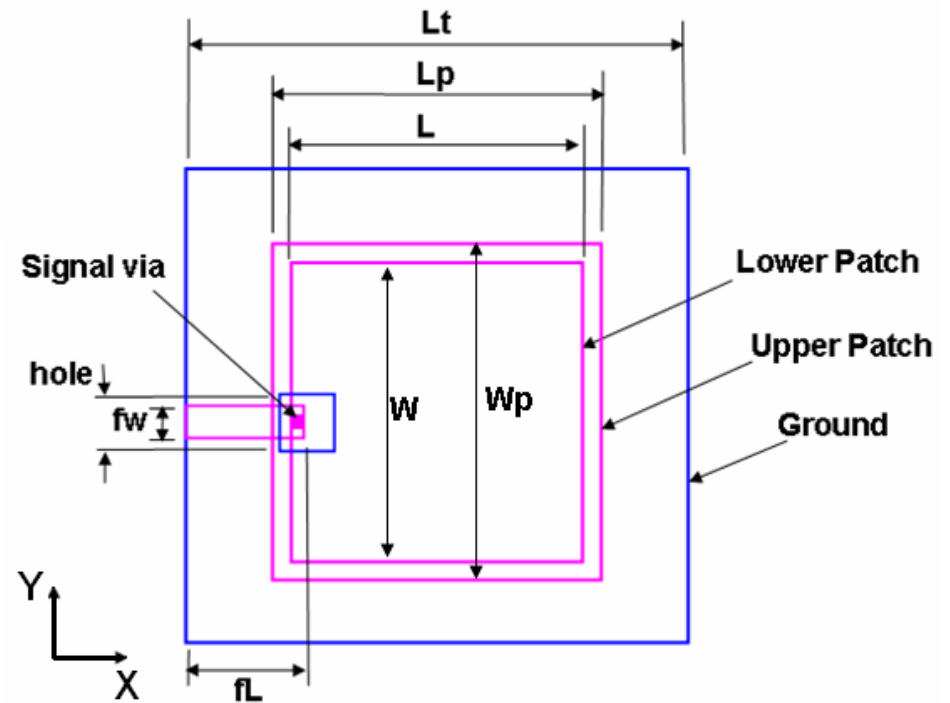
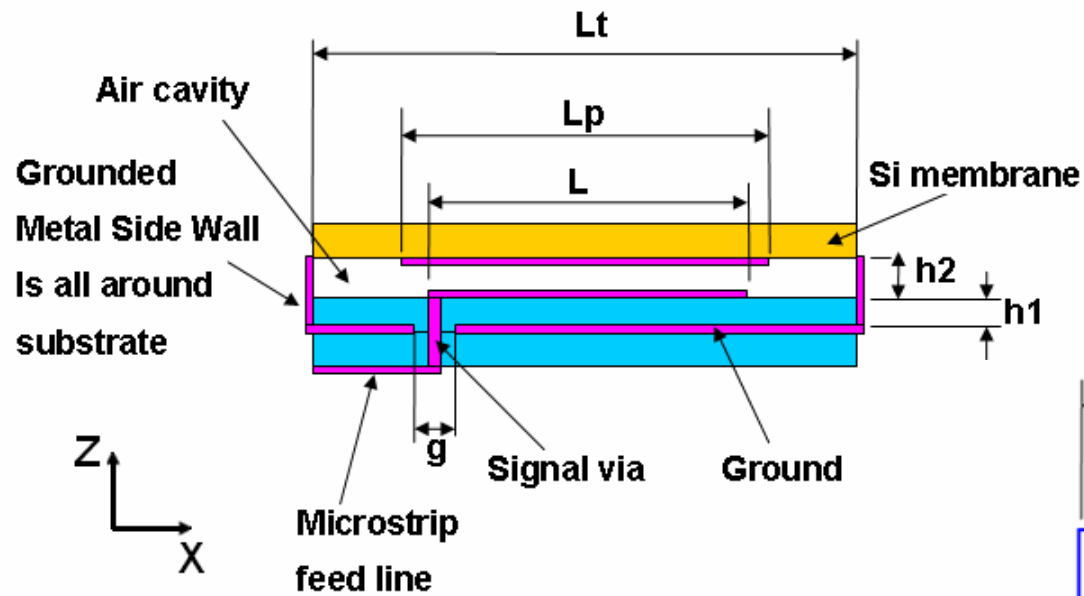
RF Wireless Pressure Transducer concept



RF Wireless Pressure Transducer



RF Pressure Transducer



30-55 GHz

$L_t = 3340 \text{ } \mu\text{m}$

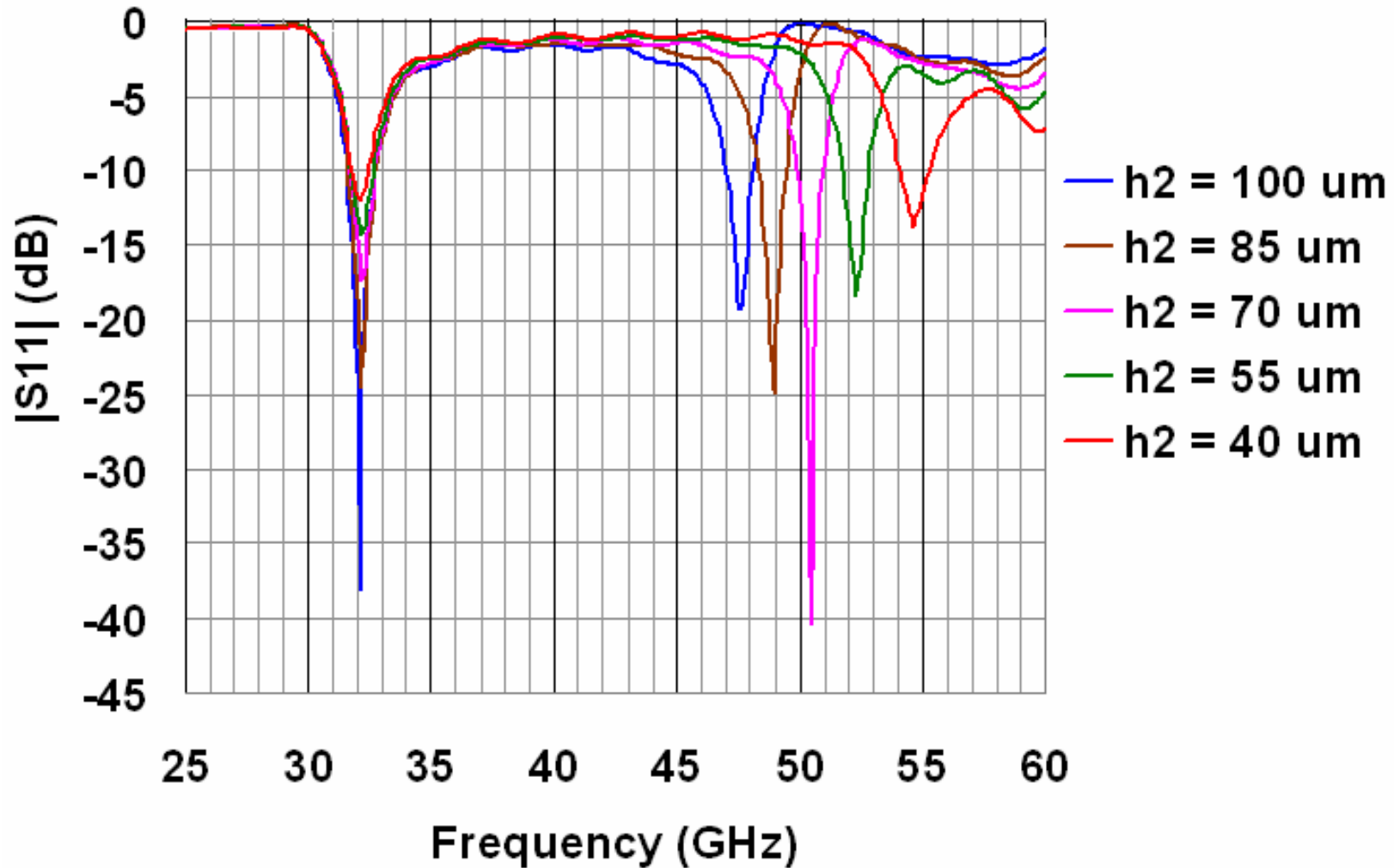
$L_p = W_p = 1800 \text{ } \mu\text{m}$

$L = W = 1670 \text{ } \mu\text{m}$

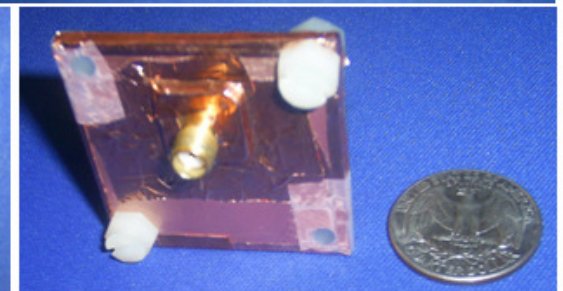
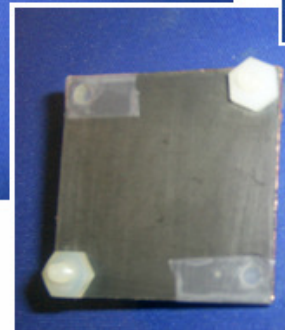
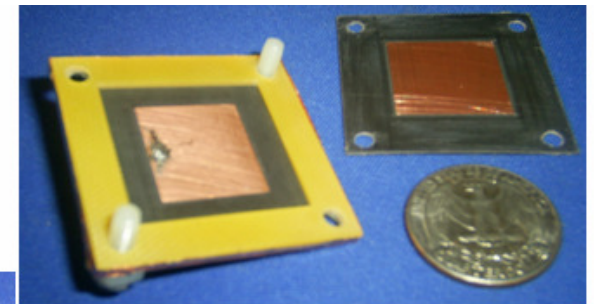
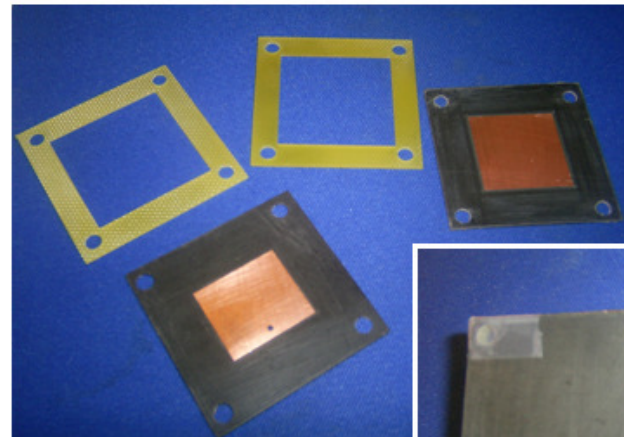
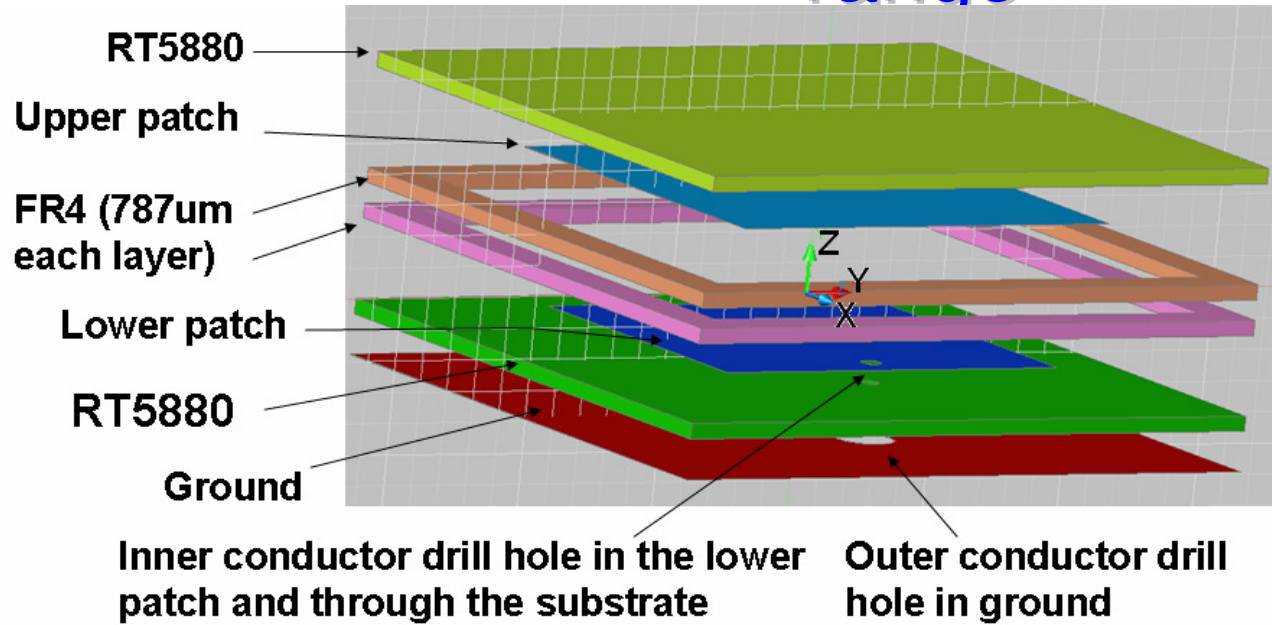
$h_1 = 82 \text{ } \mu\text{m}$

$h_2 \text{ (air gap)} = 40 - 100 \text{ } \mu\text{m}$

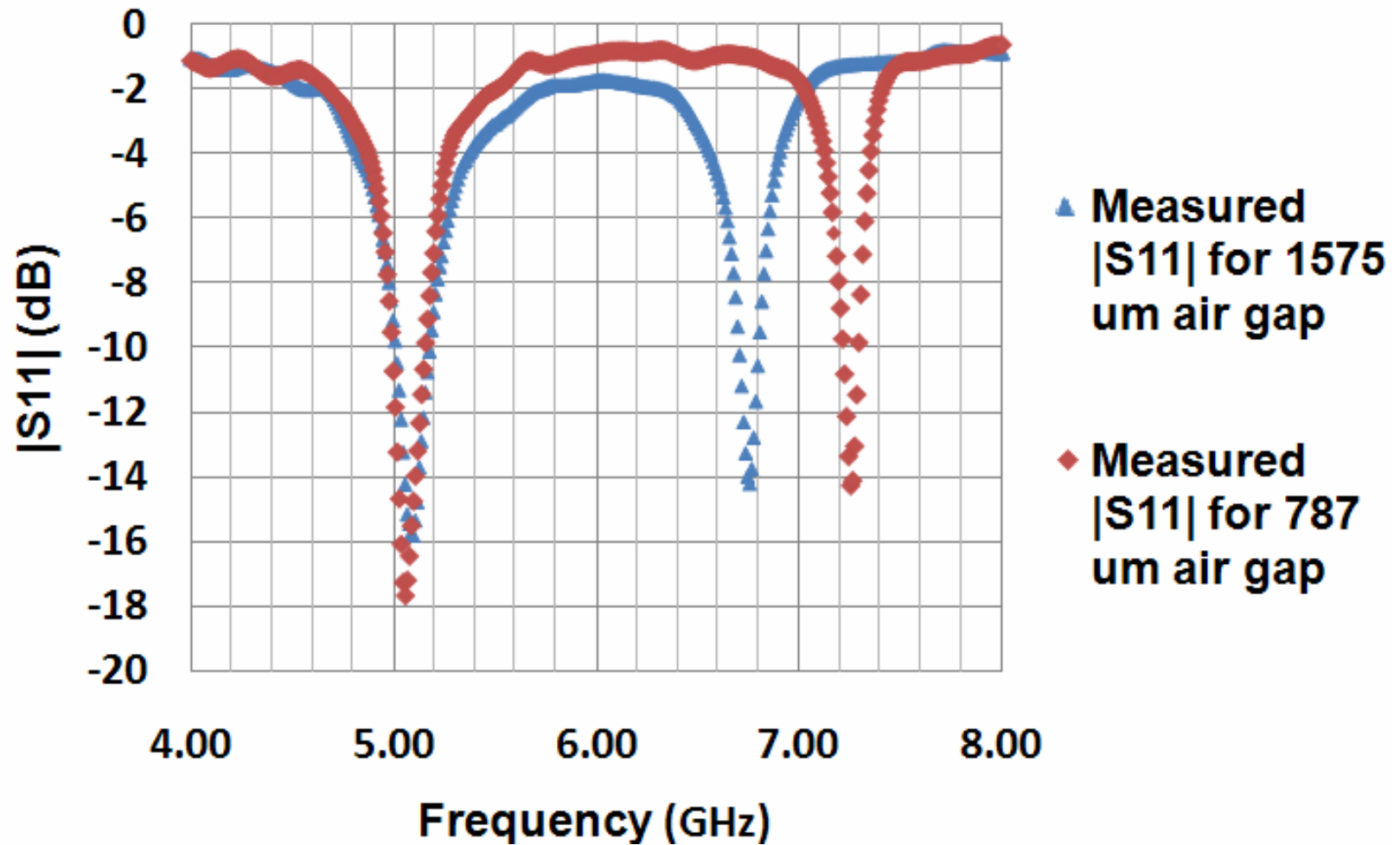
Simulation Results at 30 – 55 GHz



Prototype for Implementation at 5-8 GHz range



Measured Results at 5-8 GHz range



Conclusions

- ❑ A new highly sensitive radio frequency pressure transducer at millimeter wave frequency range.
- ❑ Seamlessly integrated with other RF circuits in the LTCC multilayer packaging technology.
- ❑ Dualband between 30-55 GHz:
 - A wireless communications link
 - A remote sensing differential pressure indicator
- ❑ Simplify the design process, reduce the device's size, and reduce power consumption of the sensor at device level
- ❑ Providing a sensitivity of 116 MHz/ μm
- ❑ Proof-of-concept prototype at 5-8 GHz: sensitivity 250 MHz / 787 μm
- ❑ Future work:
 - The millimeter wave prototype based on LTCC using Si membrane
 - Modifications for multilayer organics, such as LCP that allow realization of wireless implantable sensors for biomedical applications.

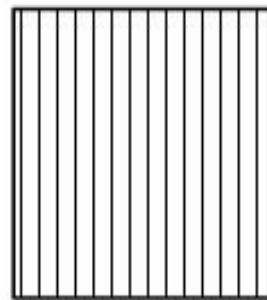
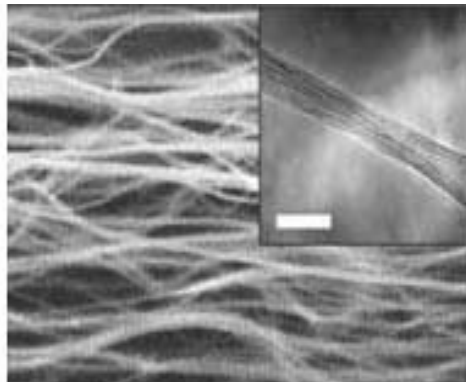
Characterization and Testing of Novel Polarized Nanomaterial Textiles for Ultrasensitive Wireless Gas Sensor

Team: Trang Thai, Justin Ratner, Gerald DeJean

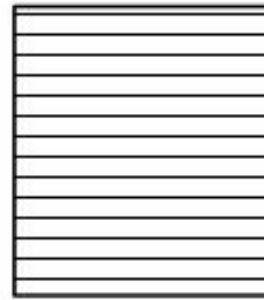
Collaborator: Wenhua Chen
(State Key Lab on Microwave & Digital Communication, Tsinghua Univ.,
Beijing, 100084, P.R.China)

Polarized Nano-material (PNM)

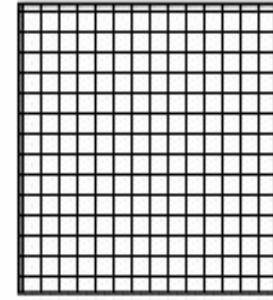
- ❑ Carbon nanotubes (CNTs) are grown on a Silicon substrate into super-aligned nanotube arrays.
- ❑ PNM samples are formed by continuous yarns of pure CNT bundles aligned parallel to one another due to van der Waals interactions.
- ❑ Highly polarized and excellent shielding effect
- ❑ Investigated at Ka-band (26.5 – 40 GHz) for millimeter wave applications such as ultrasensitive gas sensing.



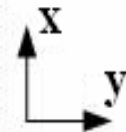
Polarization #1



Polarization #2

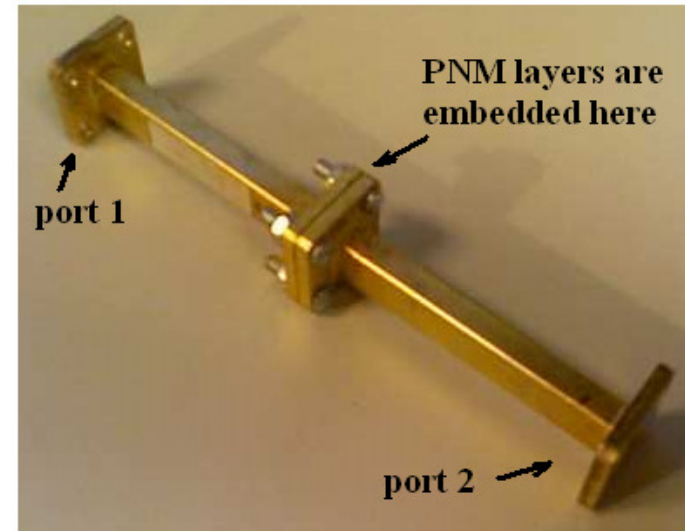


Polarization #3

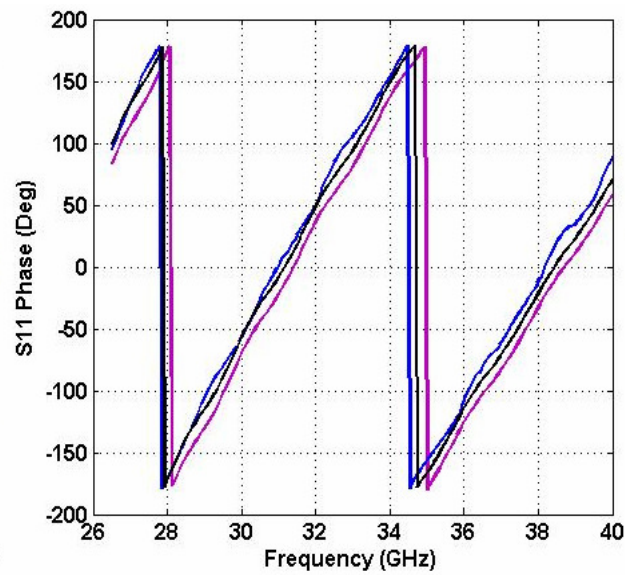
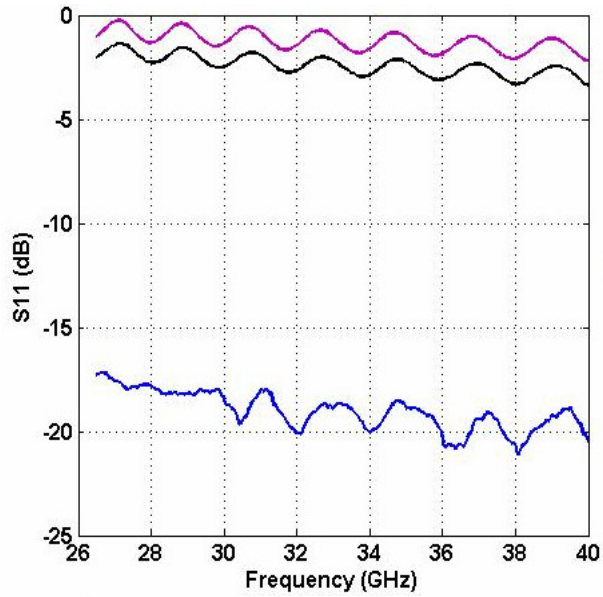


Characterization set up

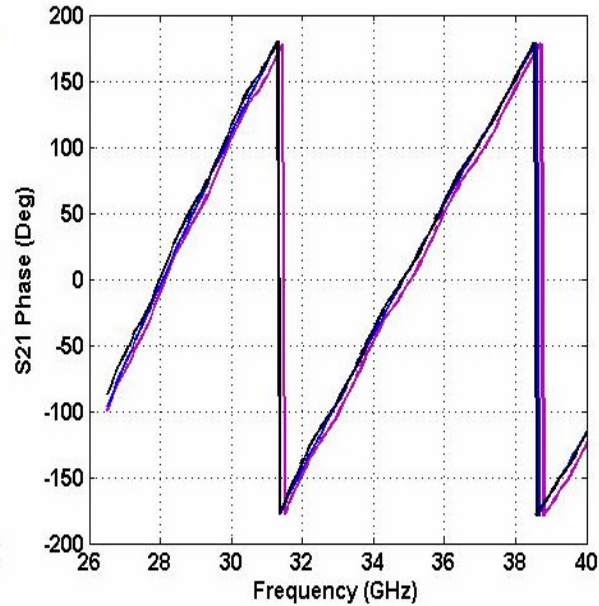
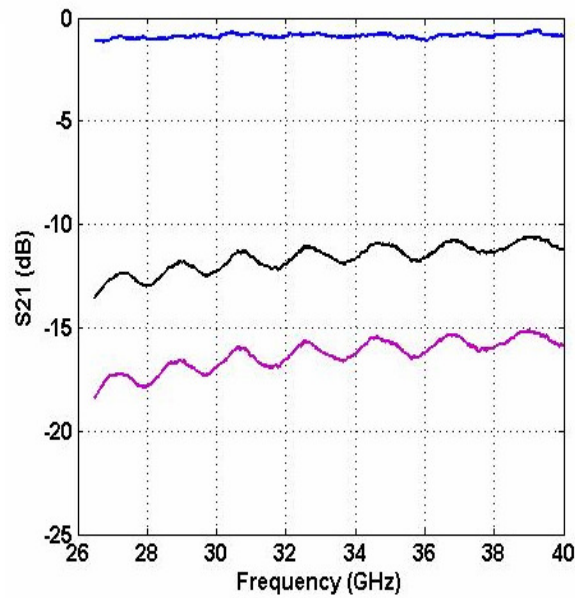
- ❑ 20 layers of PNM textile are weaved one by one on to the waveguide aperture, embedded between 2 waveguide sections.
- ❑ The waveguides are WR-28 operating in Ka-band of 26.5 – 40 GHz.
- ❑ Scattering parameters of 3 different polarization schemes are measured.



S-parameter Measurements



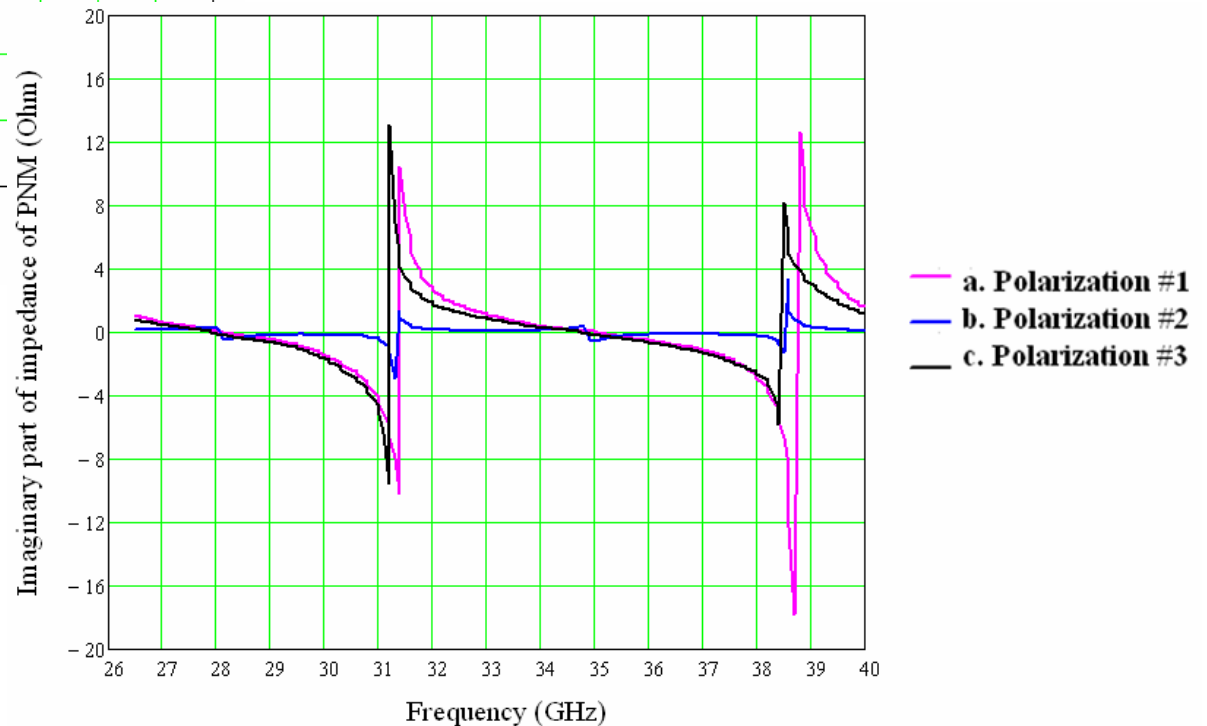
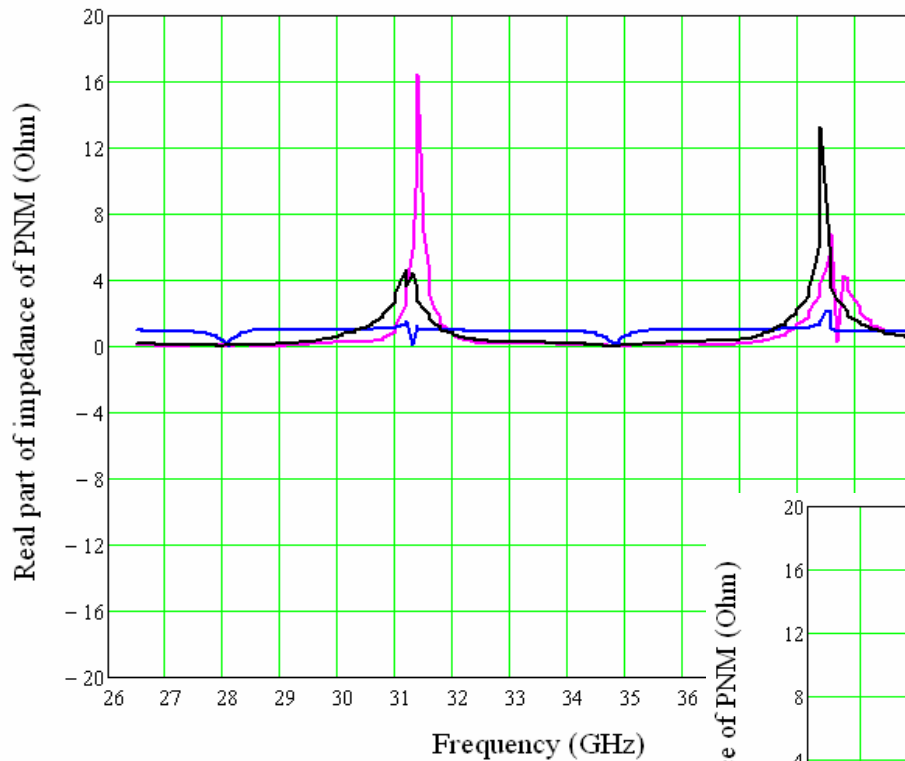
— a. Polarization #1
— b. Polarization #2
— c. Polarization #3



— a. Polarization #1
— b. Polarization #2
— c. Polarization #3

Impedance Analysis

- The impedance profiles of polarizations 1 and 3 show the distinct resonance characteristics of radiators.
- The first time the collective resonance behavior of the carbon nanotubes is shown in the microwave range due to highly aligned CNTs in the PNM layers.



Study of Graphene Nanoribbons in Microwave frequency range

Team: Trang Thai, Gerald DeJean

Collaborator: Dr. DeHeer's Expitaxial Graphene Lab
(School of Physics, Georgia Institute of Technology)

Properties and Applications

- ❑ Extraordinary electrical and mechanical properties similar to carbon nanotubes.
- ❑ Capable of being patterned into desired geometry
- ❑ High carrier mobility => ideal material for detecting THz radiation
- ❑ Passive components such as antennas and interconnects (transmission lines) => enable complete integrated graphene based electronics
- ❑ We investigate the planar epitaxial graphene structures grown on SiC substrates:
 - Conductance and scattering parameter study of GNRs in 2-port network at millimeter and sub-millimeter wave signals
 - Gas sensing capability of GNRs for highly sensitive wireless sensors

