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# Reticular Graphene Reinforced Copper for Electromagnetic Shielding Application

## The Fourth International Symposium on 3D-PEIM

### Session S5 : Manufacturing Technologies

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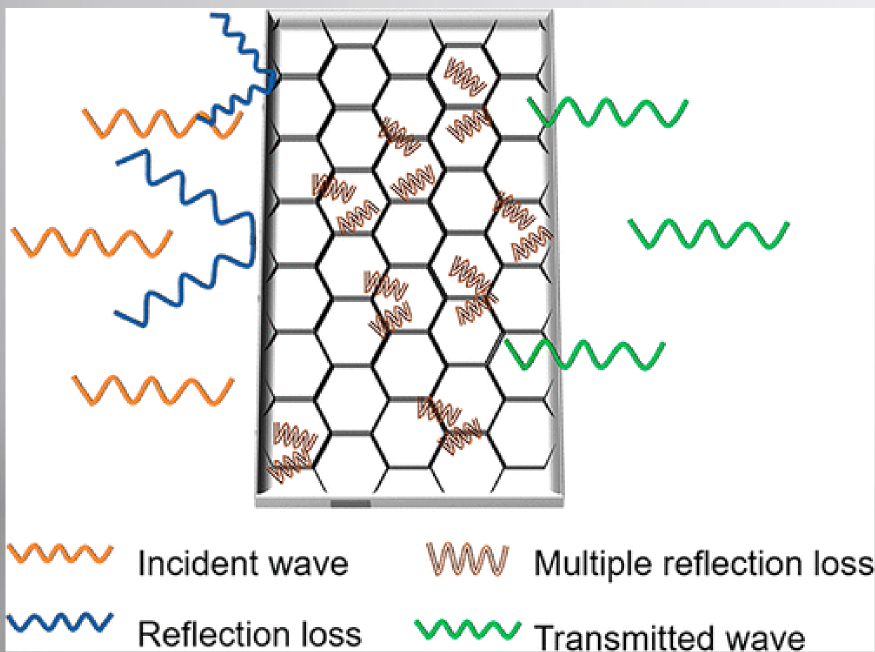
# Electromagnetic Interference (EMI) Shielding

**4th major hazard to human survival**




Jia et al. ACS Appl. Nano Mater. 2020, 3, 7, 6140-6155

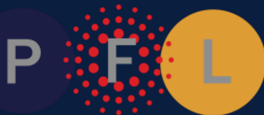
EMI shielding materials

Metal materials: iron, copper, silver

Carbon materials: CNTs, graphene, graphite

Filler-filled composites: uniformity, stratiform, cladding

Conductive coating: electroless plating, electroplate, physical coating

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# Properties of Graphene (Gr)

Single layer of one atomic thickness [0.335 nm]

High transparency
Absorbs 2.3 % of light than ITO

High surface area [2630 $m^2/g$]
< 5 gms can cover a soccer field

High thermal conductivity [1500-2500, W/m.K at RT, > diamonds]

High electron mobility [200,000 $cm^2V^{-1}s^{-1}$] 100x > than silicone [1]

Lowest known resistive material at RT [$10^{-8}$ Ω.m, 35% < than Cu]

High strength [130 GPa, 100x > than steel] , Stiffness [~ 1 TPa, comparable to diamond]

Highly stretchable
By up to 25% [though its brittle]

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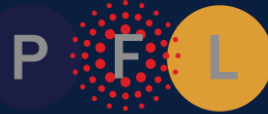


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# Why Gr Foam (GrF)?

Resin

Pure Graphene

Mxene

GF

Particle

Hybird

Hybird

Incident

Transmitted

$SE_R$

$SE_M$

Jia et al. ACS Appl. Nano Mater. 2020, 3, 7, 6140-6155

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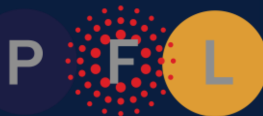


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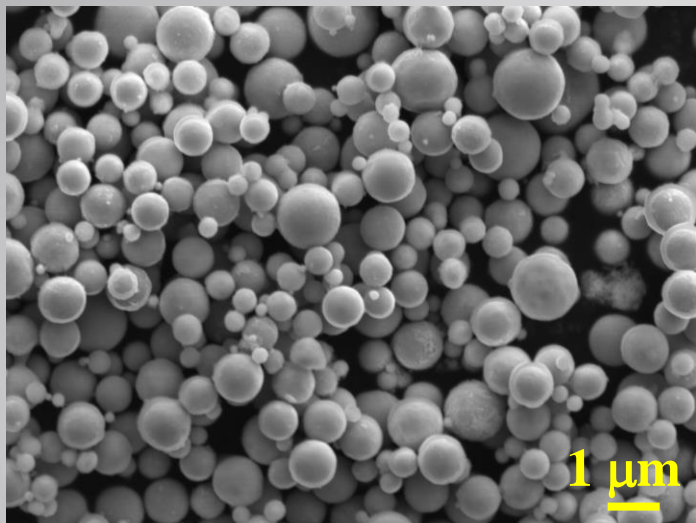
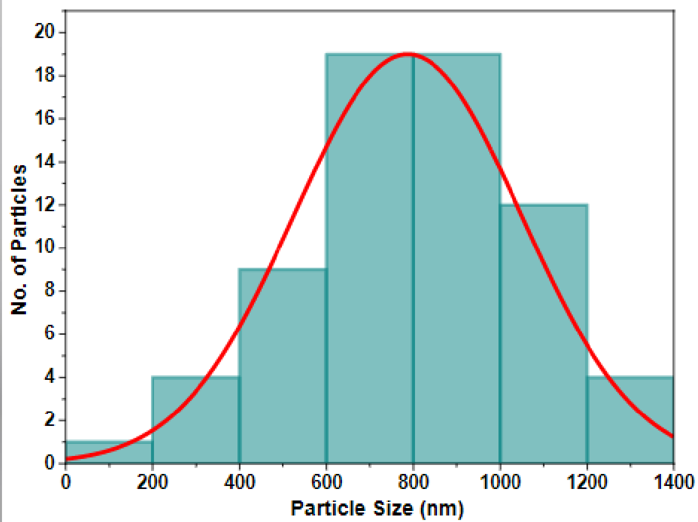
# Starting Materials

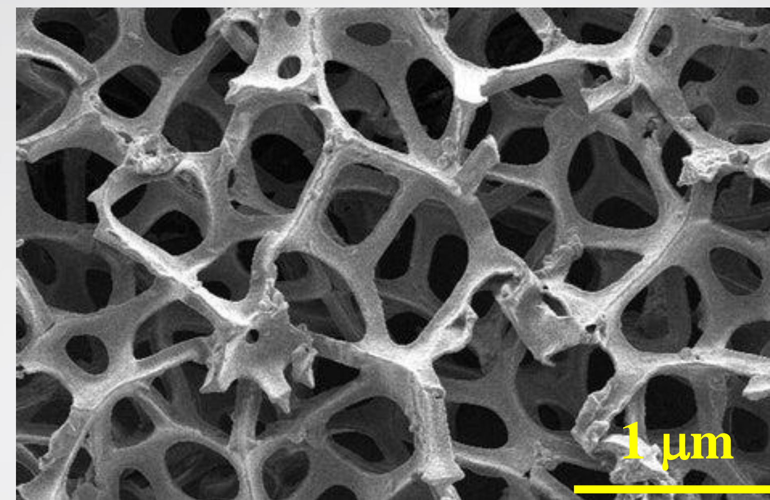
## Sub-micron Cu powder




CNPC powder North America Inc., BC, Canada

## Ultra-Light Freestanding 3D Graphene Foams



https://graphene-supermarket.com/3D-Graphene-Foams/

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# Processing via Spark Plasma Sintering (SPS)

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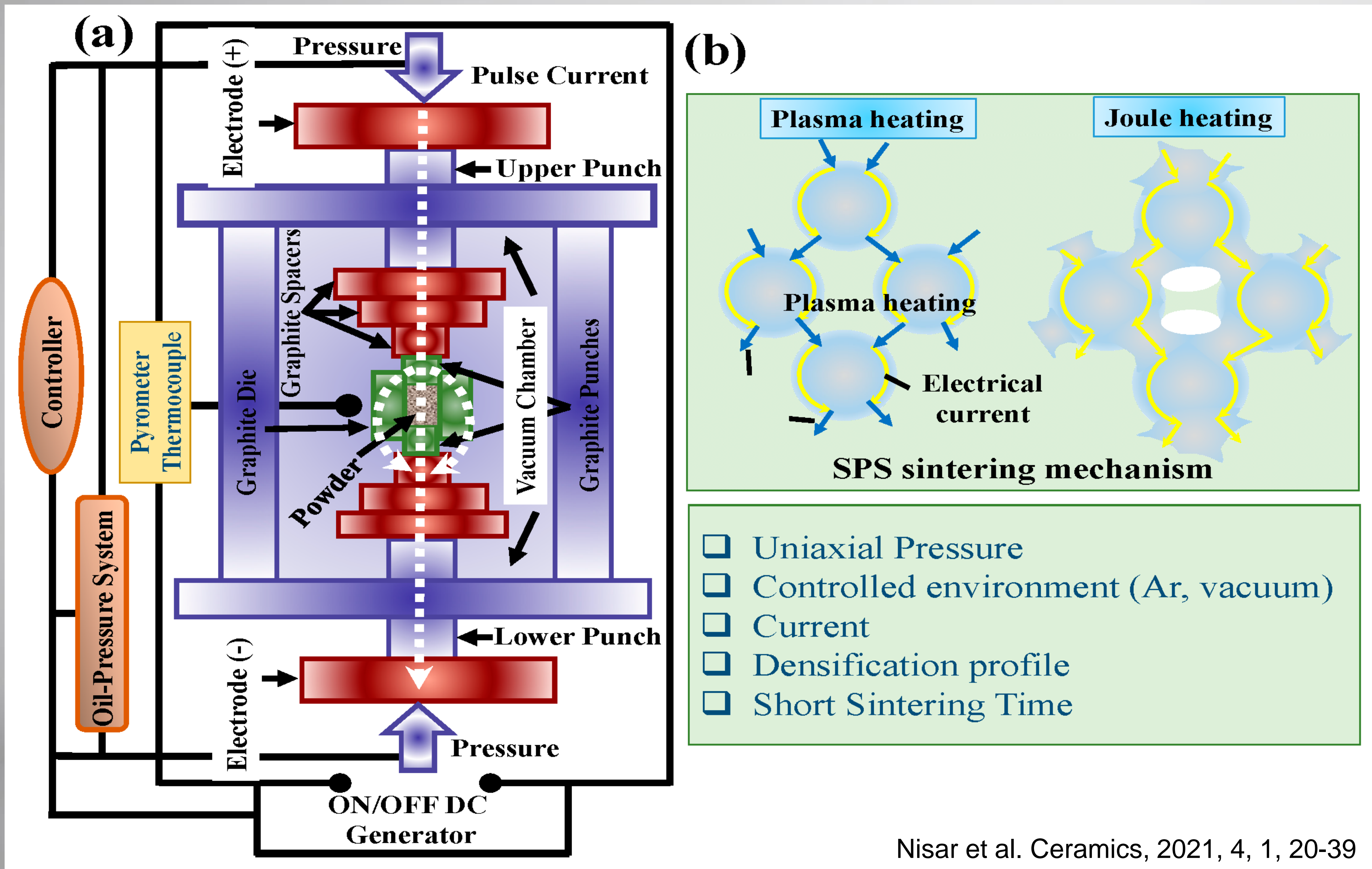


- ❑ Uniaxial Pressure
- ❑ Controlled environment (Ar, vacuum)
- ❑ Current
- ❑ Densification profile
- ❑ Short Sintering Time

Nisar et al. Ceramics, 2021, 4, 1, 20-39

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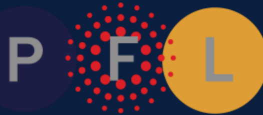


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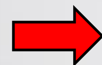
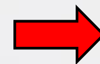
# Cu decorated GrF

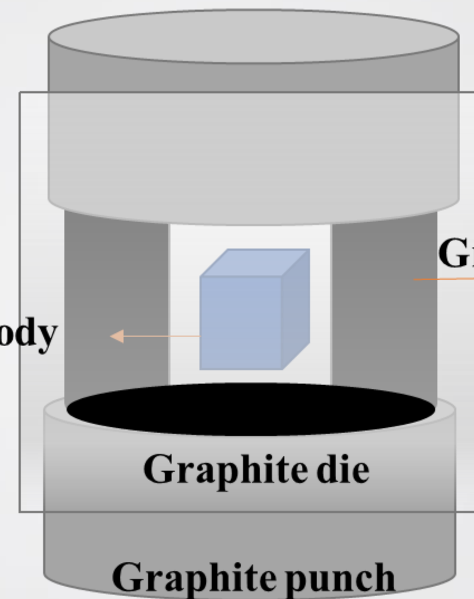
Cu slurry

Dip coating



Air Drying






Presssureless SPS

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# Process Scheme of Layered Architecture

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Cu powder
Press
Cu
Cu decorated GrF
Press
SPS
Graphite sheet
Graphite punch
Graphite die
SPS
Cu
Cu decorated GrF
Cu
Cu powder
Cu decorated GrF
Layered Structure

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Adapted from Nisar et al. accepted in Carbon, 2023

# Processing Parameters

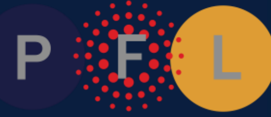
**Processing details:**

- Spark Plasma Sintering
- Temperature : 950 °C, Time: 10 min
- Vacuum environment
- Heating rate : 100 °C/min

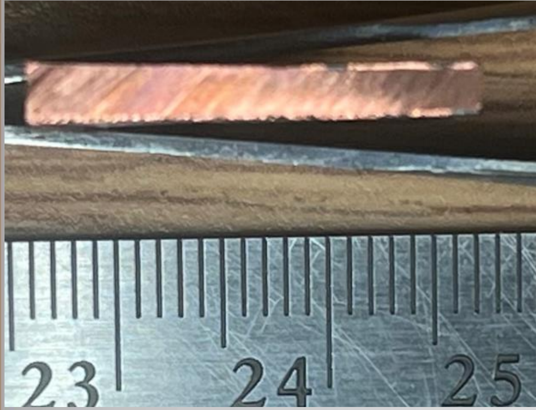
The reticulated structures of GrF-reinforced Cu matrix composites:

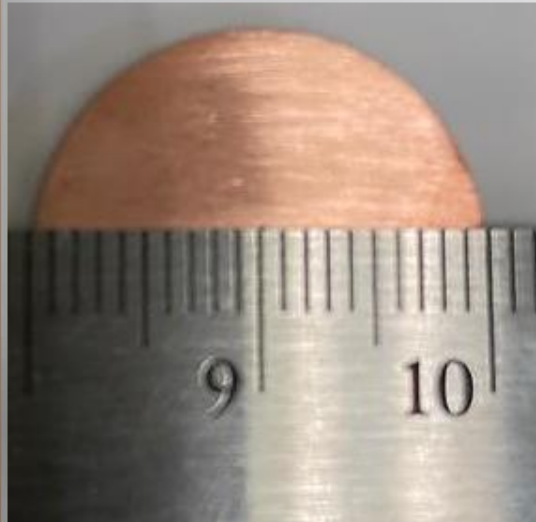
(i) Sintered Cu decorated GrF sandwiched between Cu powder bed at a pressure of 5 MPa.

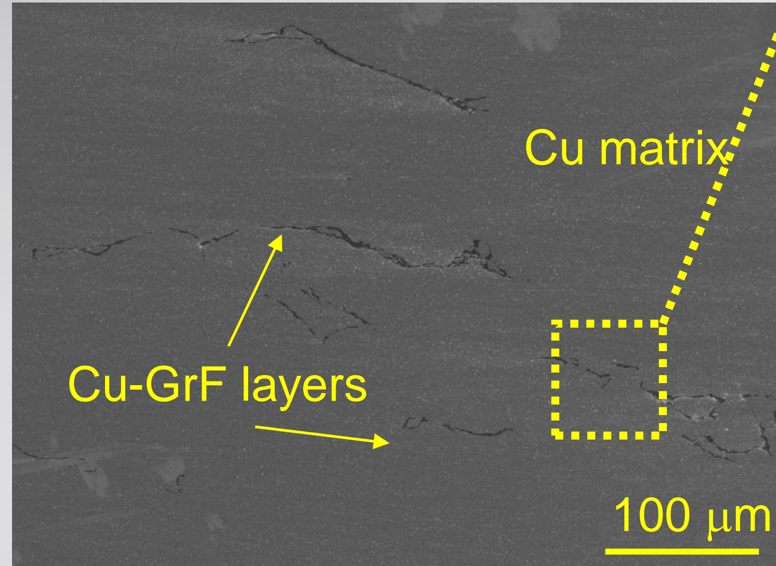
(ii) Sintered Cu decorated GrF sandwiched between Cu powder bed without pressure.

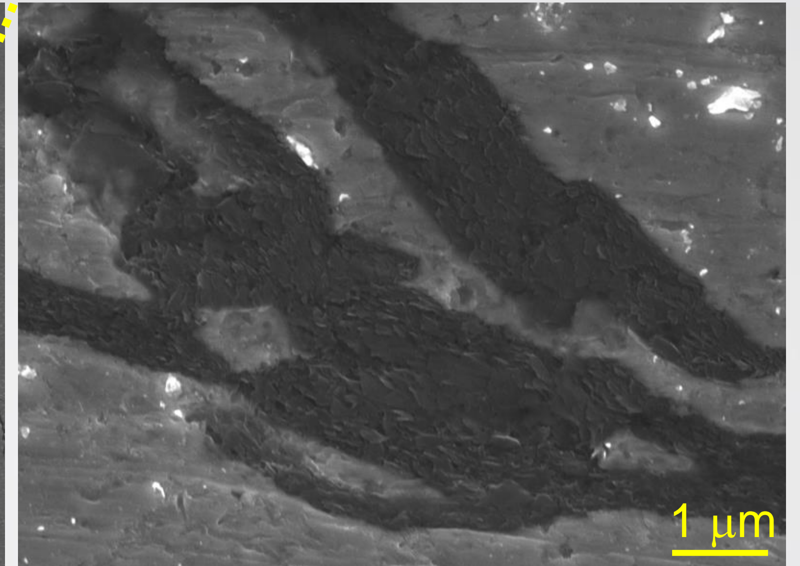


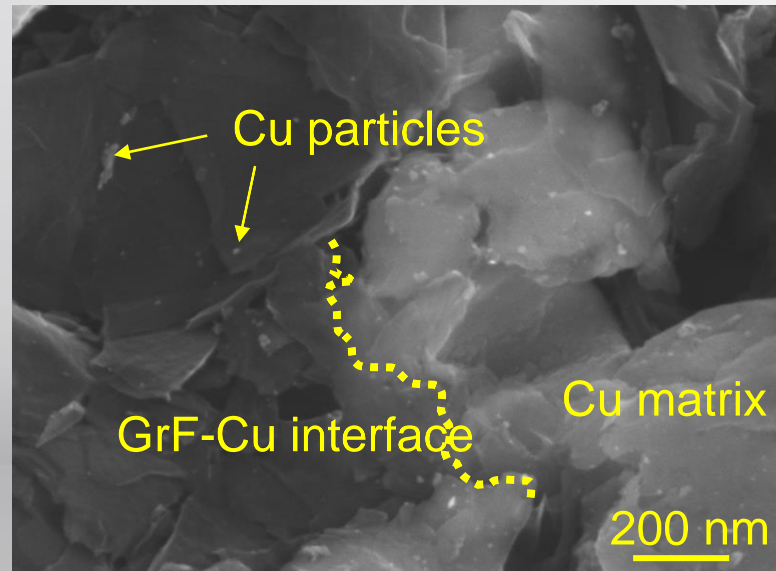

# Approach 1: With Pressure

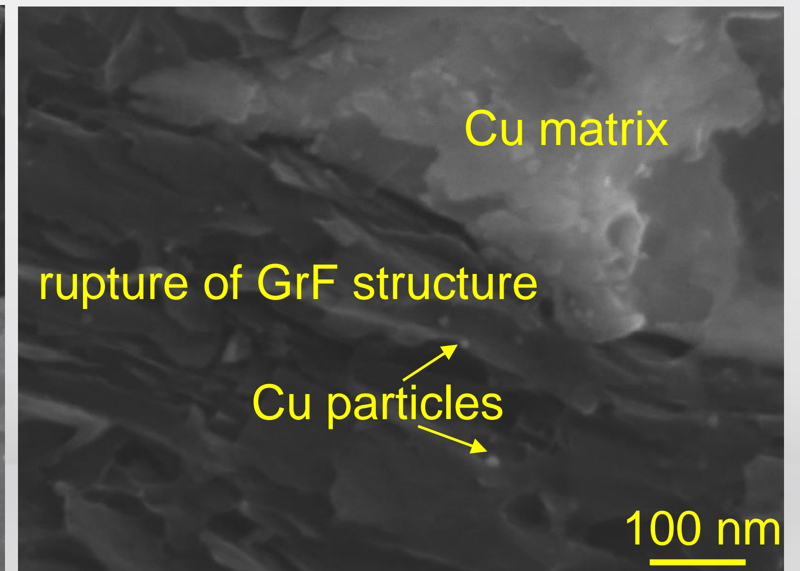
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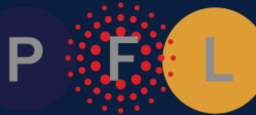


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# Approach 2: Without Pressure

Top Surface

Bottom Surface

Relatively Dense

Porous

Post-filling

Post-filling

Interface

Top

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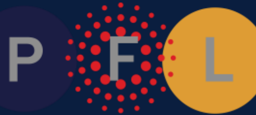
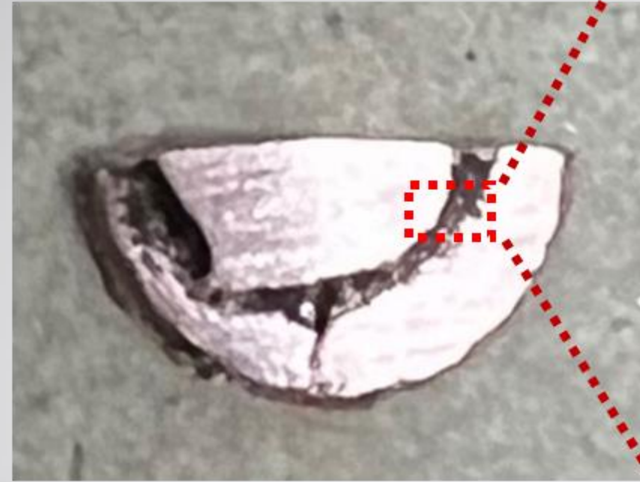
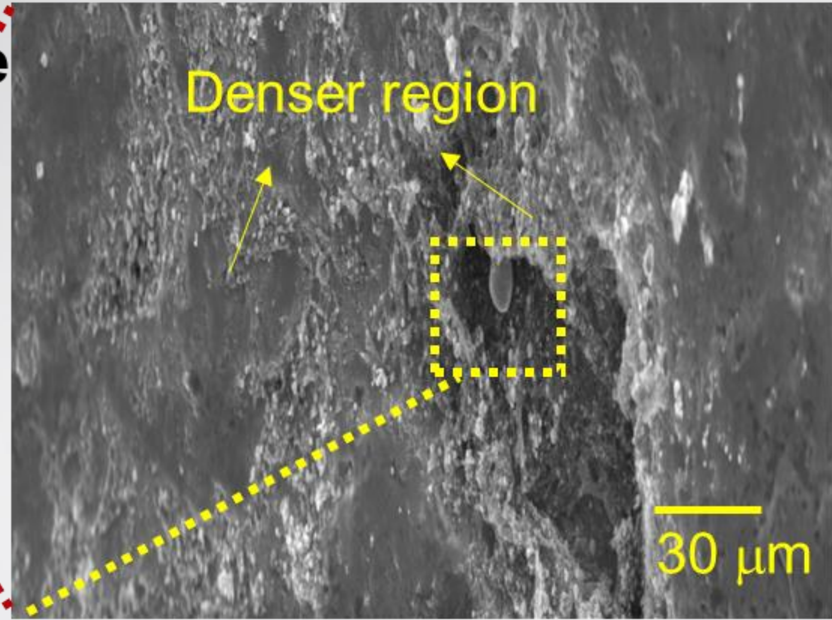
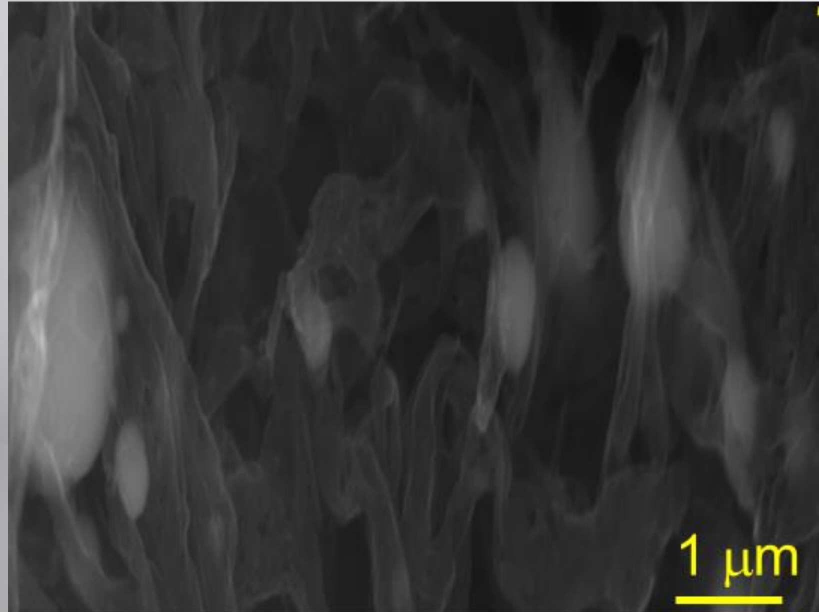
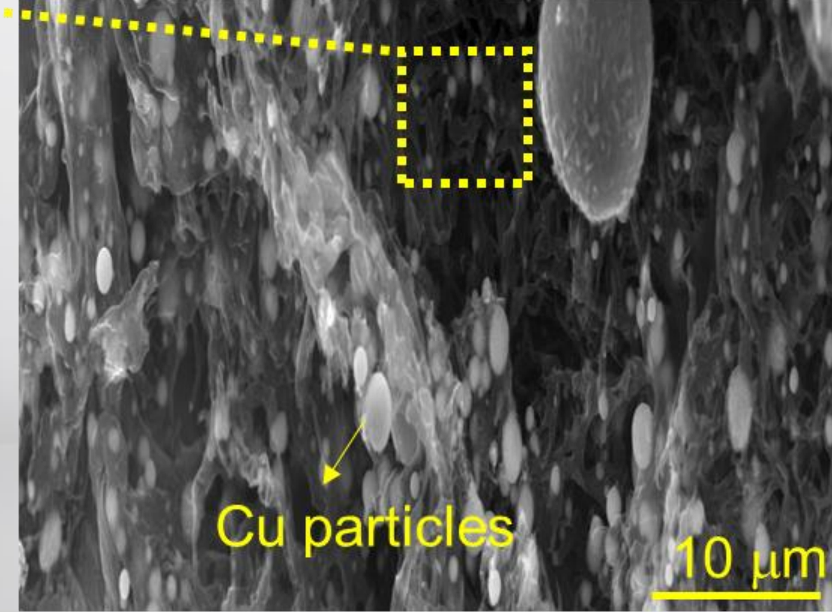
# Microstructural Analysis of Dense Cu-GrF

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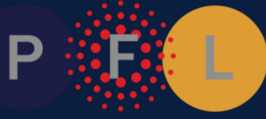
# Microstructural Analysis of Porous Cu-GrF

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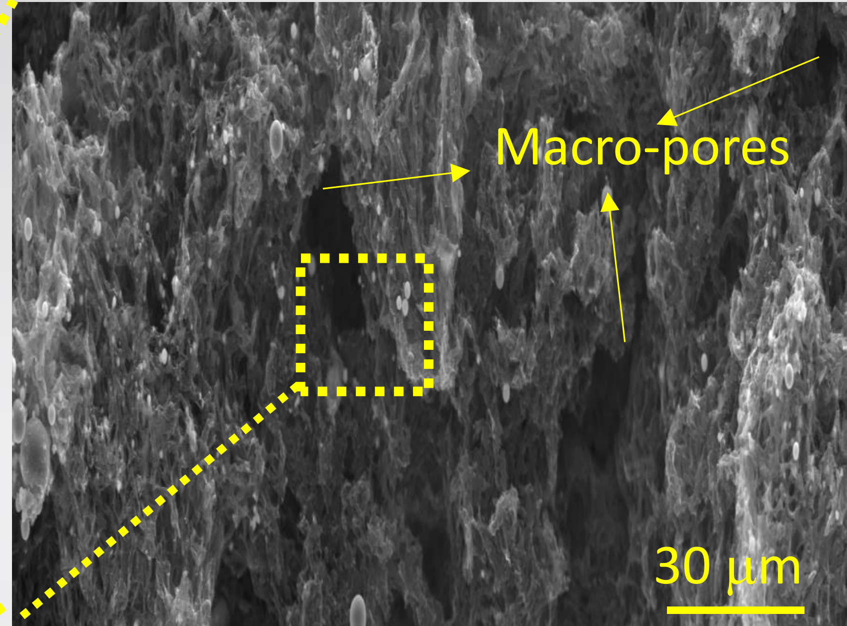
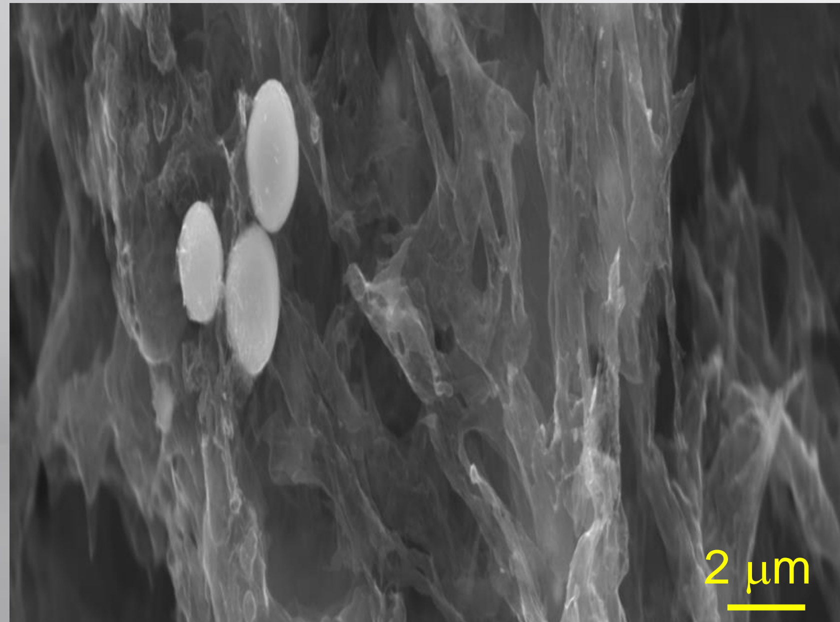
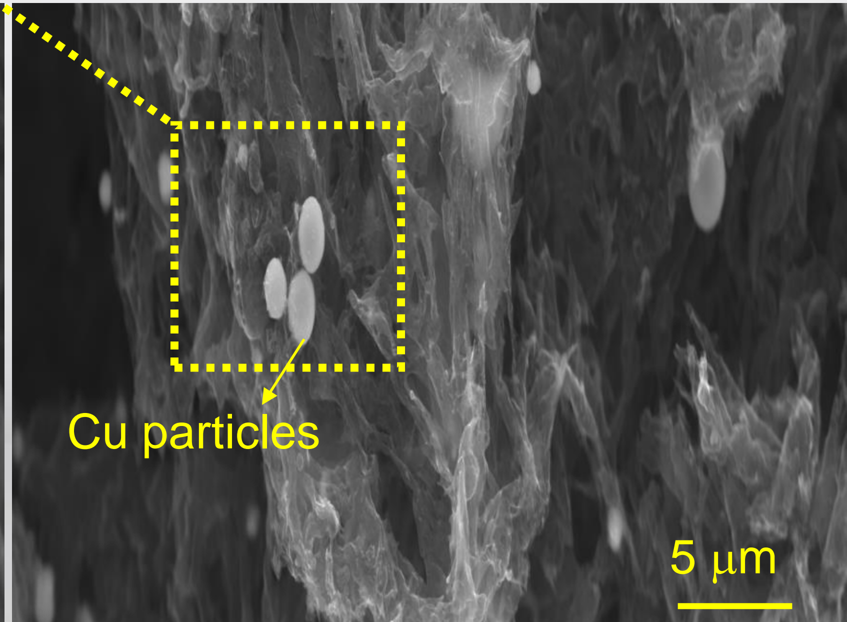
**(b) Bottom Porous-Surface**

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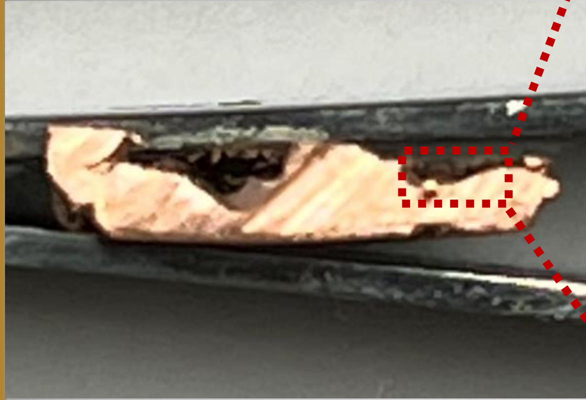
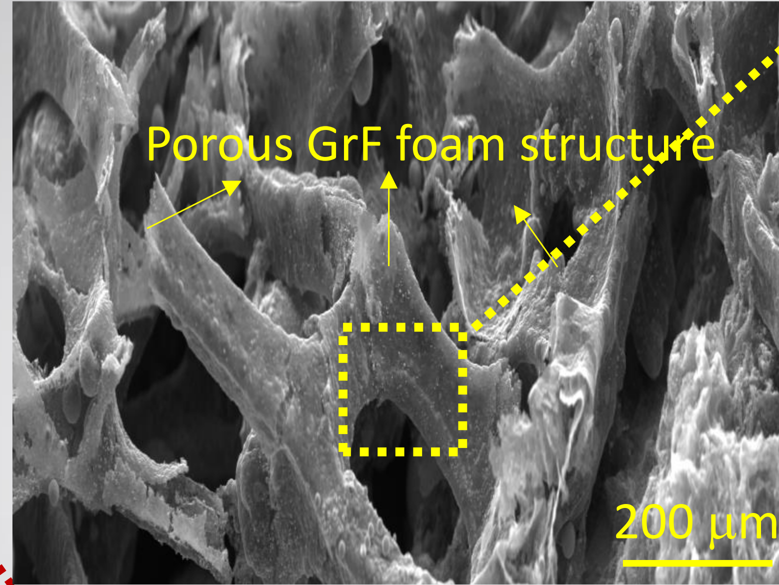
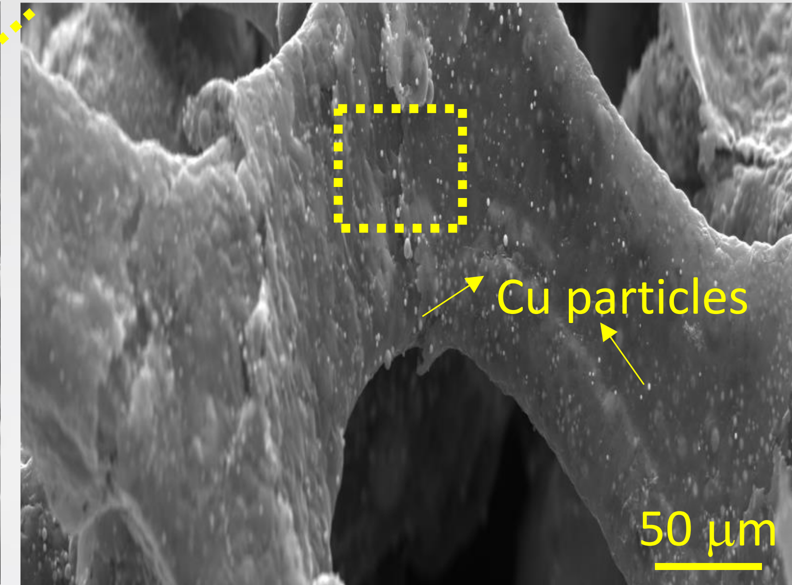
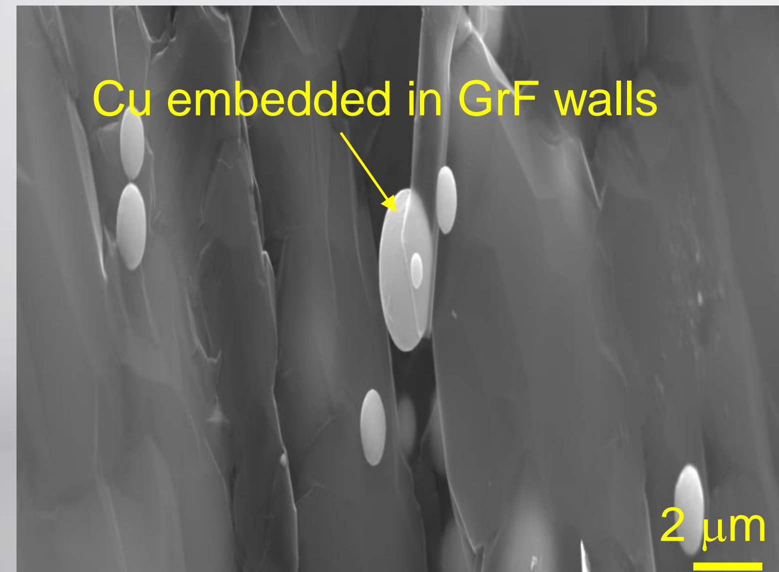
# Microstructural Analysis of Cu-GrF Interface

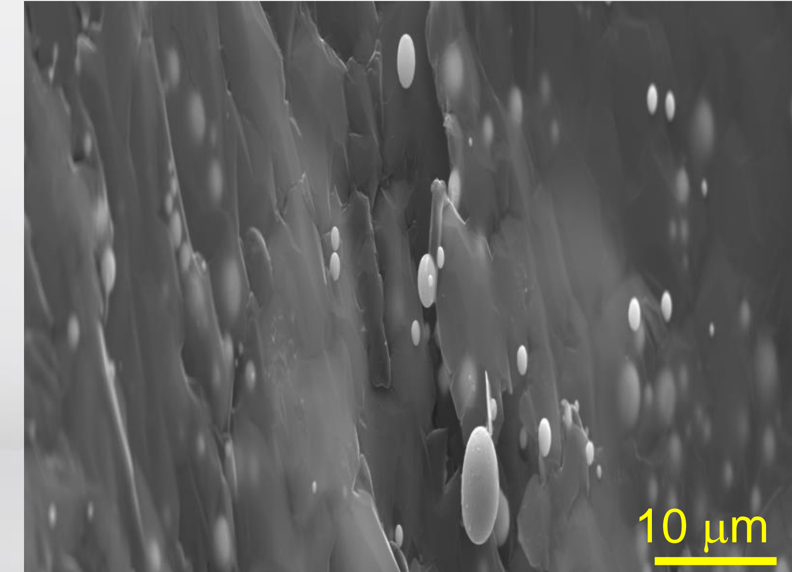
(c) Cross-section



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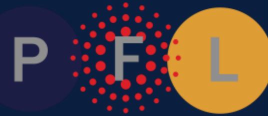


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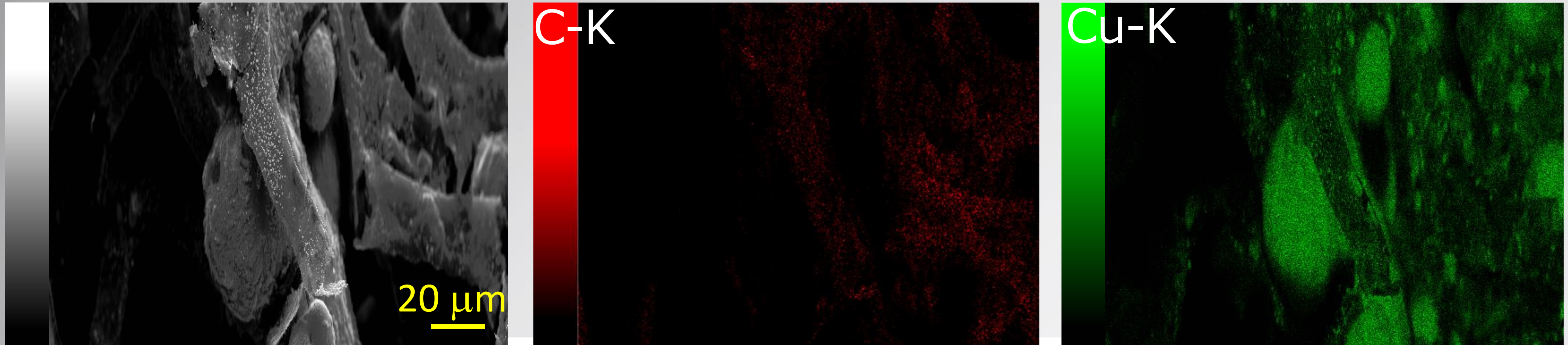
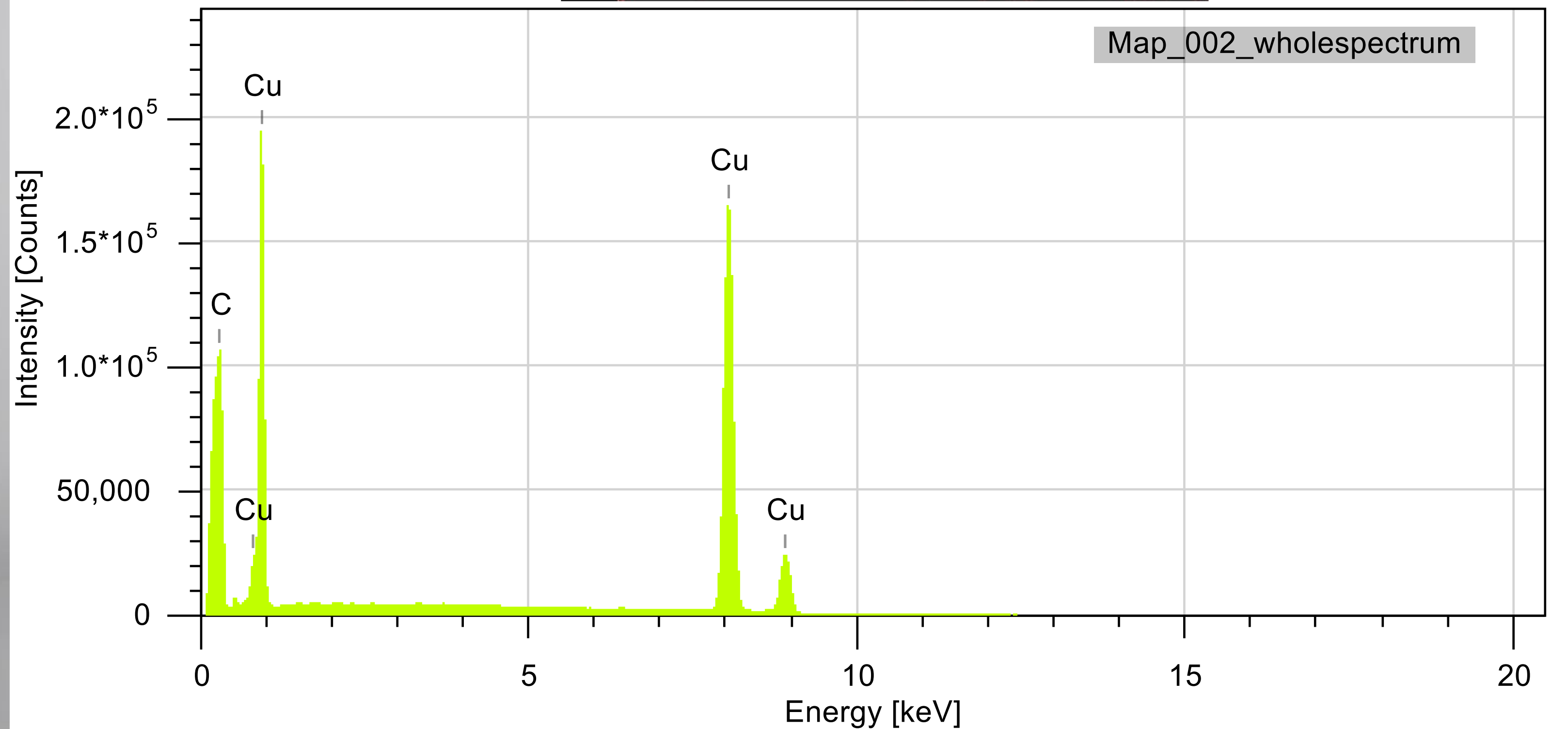
# Compositional Analysis

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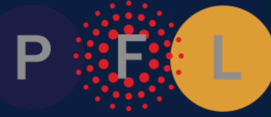

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# Shielding Effectiveness Test Setup

(a)
SHIELD
RECEIVING LOOP
TRANSMITTING LOOP
$2R_0$
$2R_0$
$2R_0$
$2R_0$

(b)
SHIELD
RECEIVING LOOP
TRANSMITTING LOOP
$2R_0$
$2R_0$
$2R_0$
$2R_0$

(c)
SHIELD
RECEIVING ROD ANTENNA
TRANSMITTING ROD ANTENNA
$d$
$d$

Shielding effectiveness set up based on the standard field source (a) magnetic field-NSA 65-6, (b) magnetic field-IEEE 299, and (c) electric field-IEEE 299

$$SE = S_{21}(\,with\ Shield) - S_{21}(\,w/o\ Shield)$$

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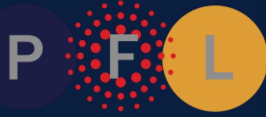
# Shielding Effectiveness of Cu-GrF structure

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Shielding effectiveness [dB]

Frequency [MHz]

Cu
Cu-Gr

(a) Magnetic field-NSA 65-6

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# Shielding Effectiveness of Cu-GrF structure

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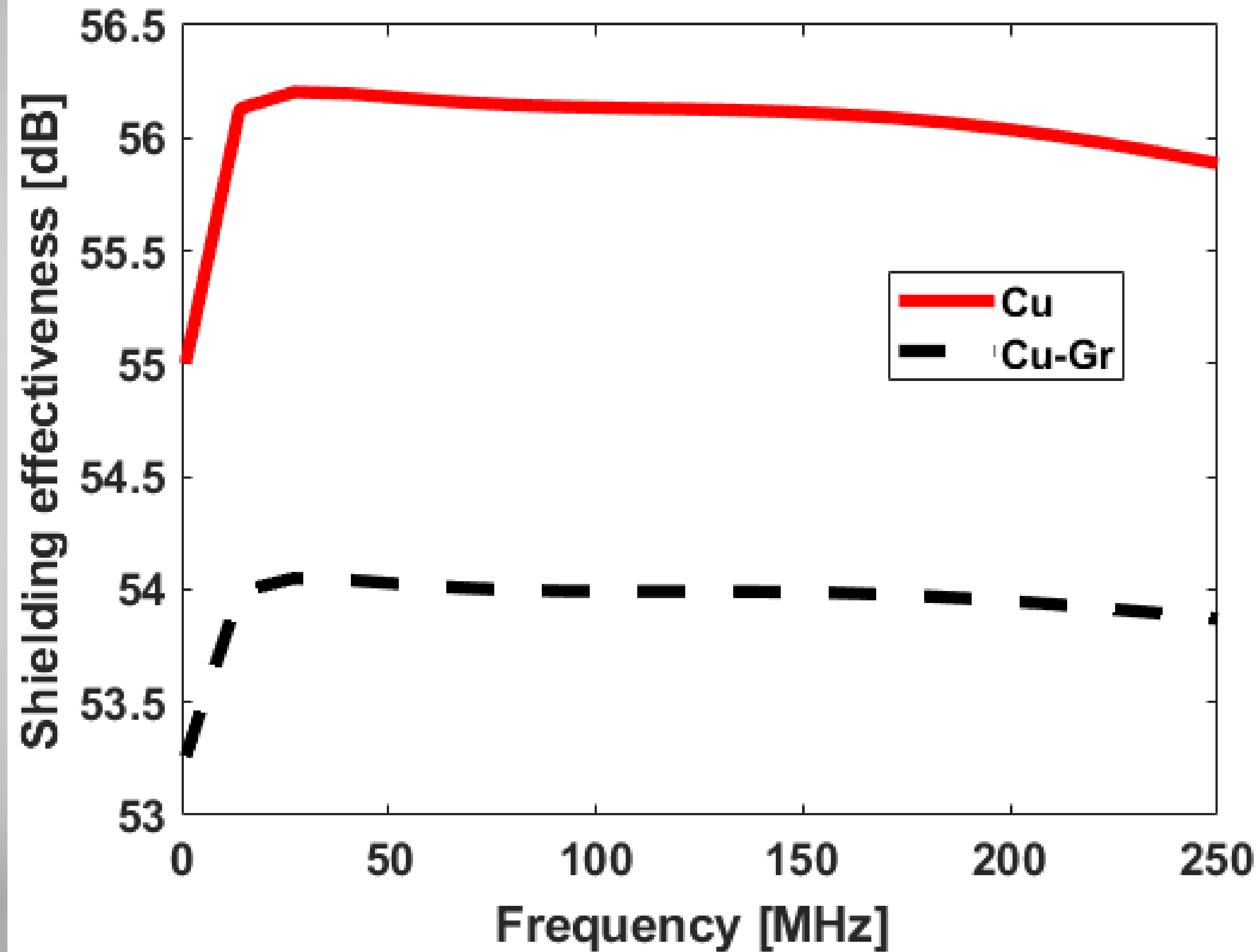


**(b)** Magnetic field-IEEE 299

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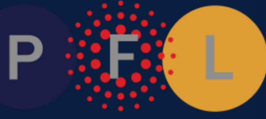
# Shielding Effectiveness of Cu-GrF structure

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Cu
Cu-Gr

Shielding effectiveness [dB]

48
47
46
45
44
43
42

0 50 100 150 200 250

Frequency [MHz]

**(c)** Electric field-IEEE 299

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# Shielding Effectiveness mechanism in Cu-GrF structure

0.5 mm Cu

0.5 mm Cu

0.5 mm Cu

1µm Cu decorated GrF

0.5 mm Cu

Incident wave

Reflected wave

Incident wave inside shield

Transmitted wave

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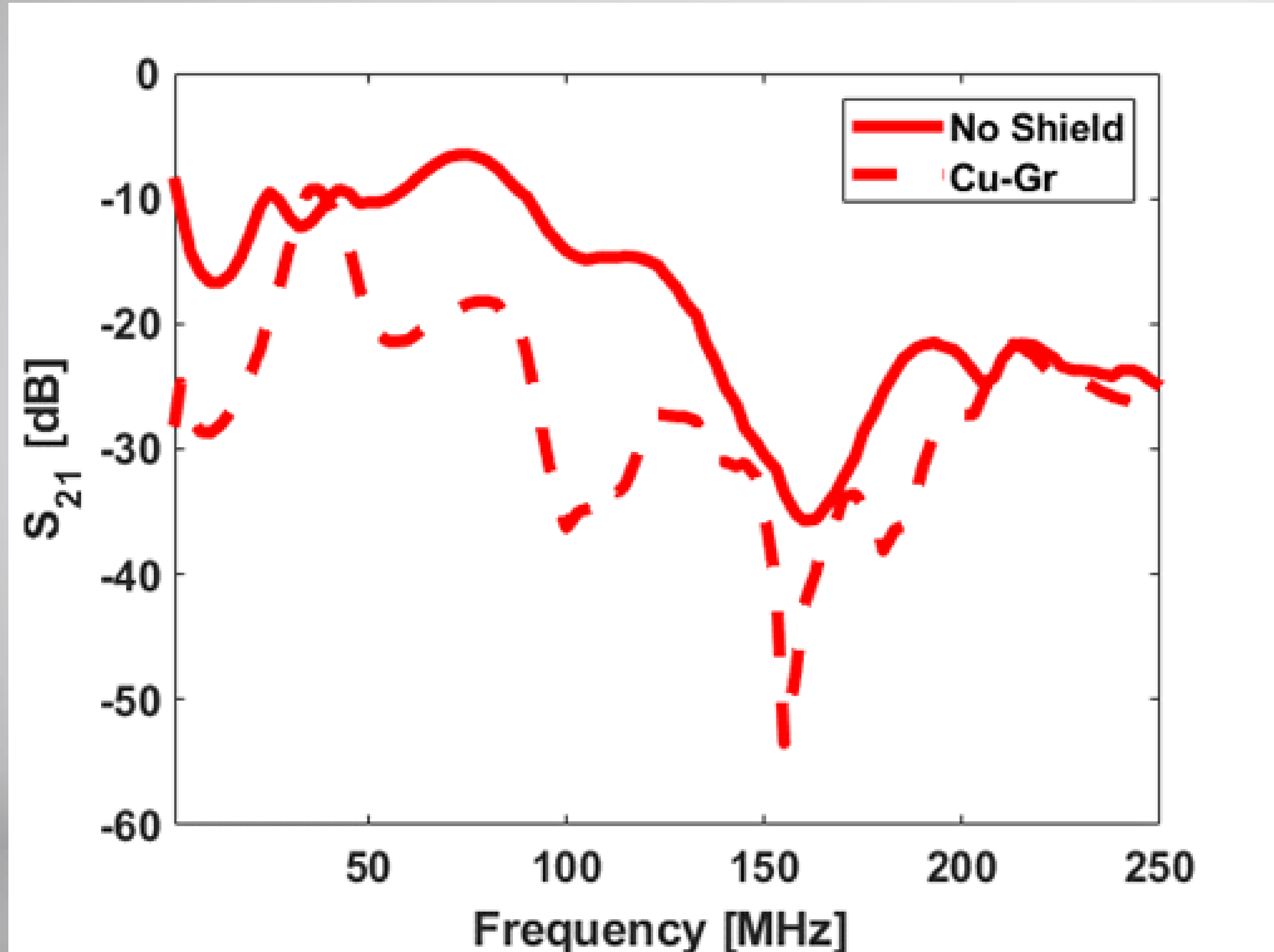
# Shielding Effectiveness measurements with NSA 65-6 standard

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P F L
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# Conclusions

Successful fabrication of layered Cu-GrF structure by SPS.

Dense Microstructure → SPS with Pressure
Porous Microstructure → SPS without Pressure

Strong Cu-GrF bonding irrespective of pressure and pressureless-sintering.

As per NSA 65-6 standard, SE is
Cu sample: 60 dB
Cu-GrF: 40-120 dB

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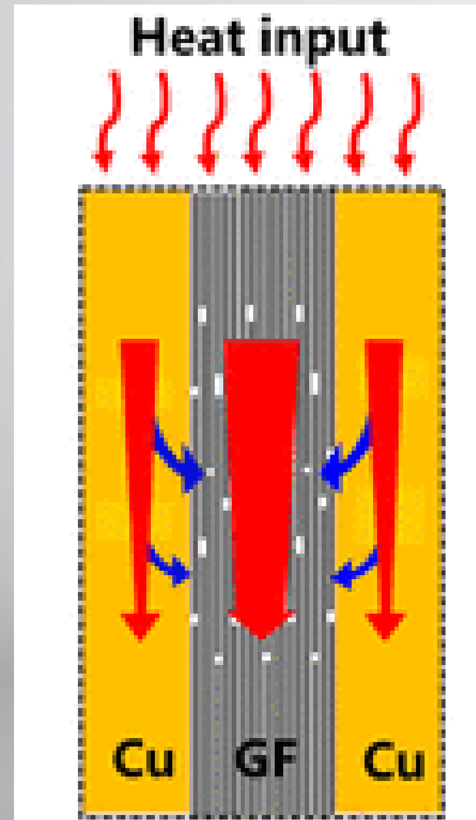
# Future Directions

Multi-layered Cu-GrF structure fabrication by SPS.

Electrical and Thermal Conductivity measurements of Cu-GrF structure

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# Acknowledgments

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*Thank You For Your Attention!*