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Design of a Circular Slotted Microstrip Patch Antenna and Improving the Gain by Incorporating RGO And RGO-Based Nanocomposites For S-Band Communications

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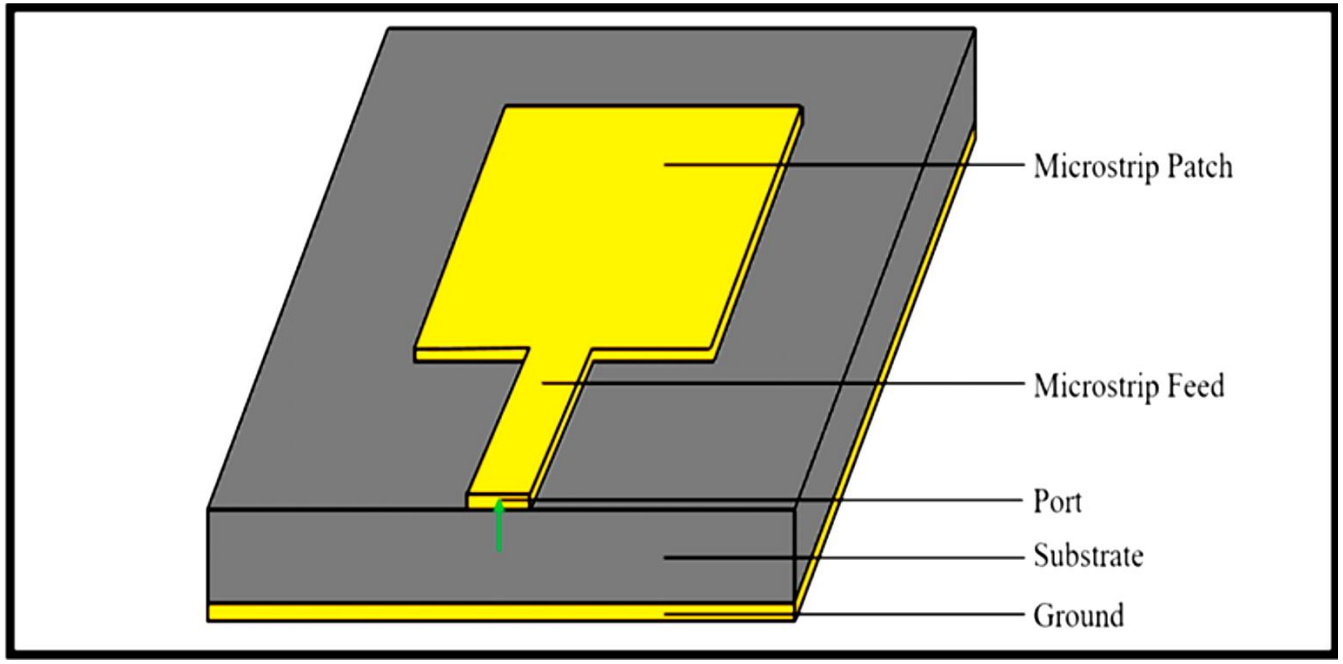
MICROSTRIP PATCH ANTENNA (MPA)

According to the Institute of Electrical and Electronics Engineers (IEEE), an antenna is defined as "a means for radiating or receiving radio waves." In other words, an antenna can be described as a system of elevated conductors that matches the transmission or reception of signals between a transmitter and a receiver to free space.

Ease of fabrication using printed circuit technology, compact, low-profile and lightweight design, cost-effective and capable of operating at two or three frequencies



The geometry of a microstrip patch antenna [1]

ANTENNA PARAMETERS

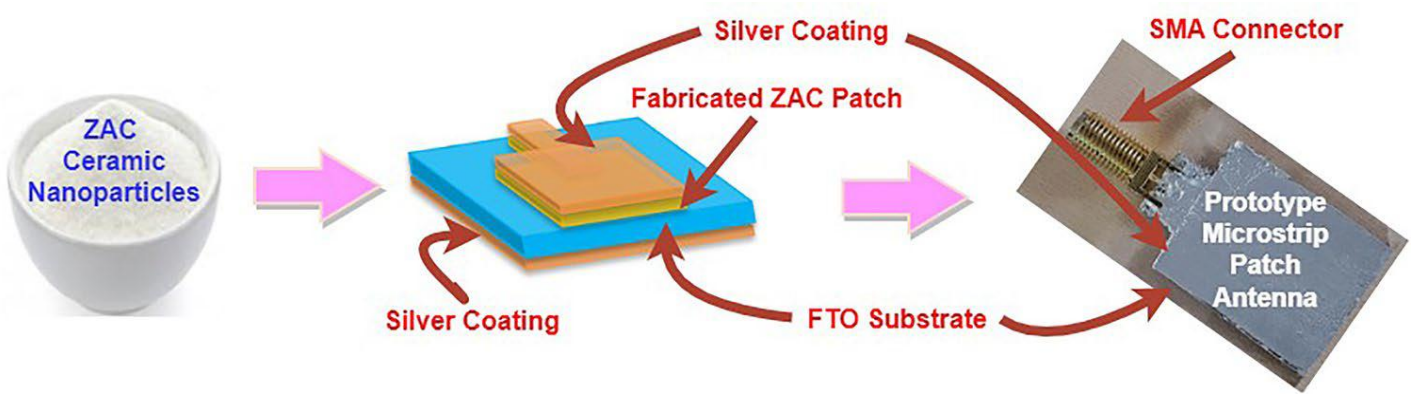
RETURN LOSS: The acceptable return loss value for the antenna should be greater than 10dB (below -10dB). Related to S-parameters.

GAIN: G = η*D, η = Efficiency and D = Directivity

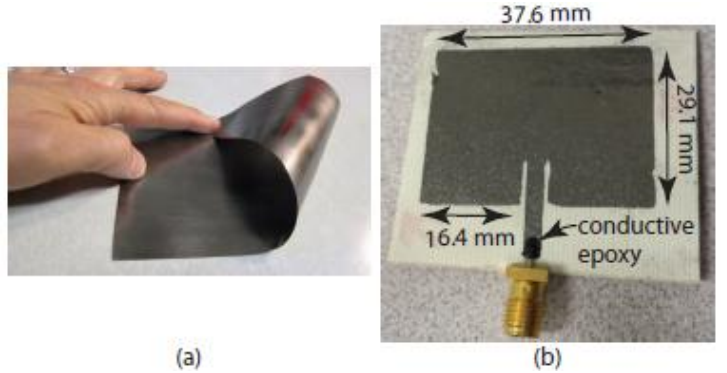
RADIATION PATTERN: A visual depiction of an antenna's radiation characteristics as a function of space

BANDWIDTH: Range of frequencies over which the antenna can operate correctly

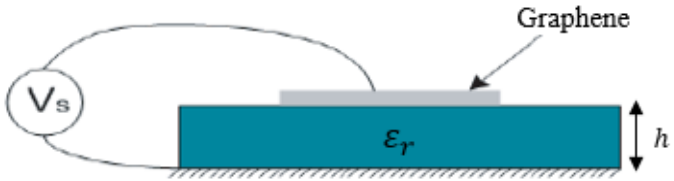
Literature and Motivation



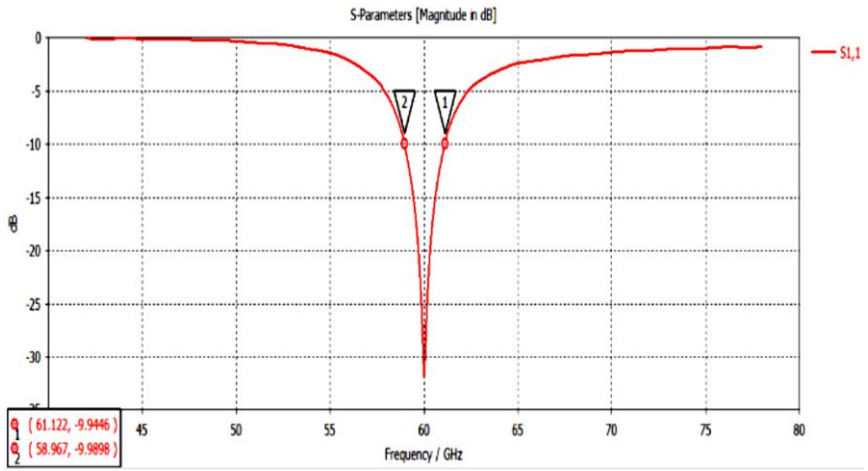
Return losses of − 25.78 dB at 2.8 GHz (S-band) and − 28.5 dB at 4.8 GHz (C-band) [2]



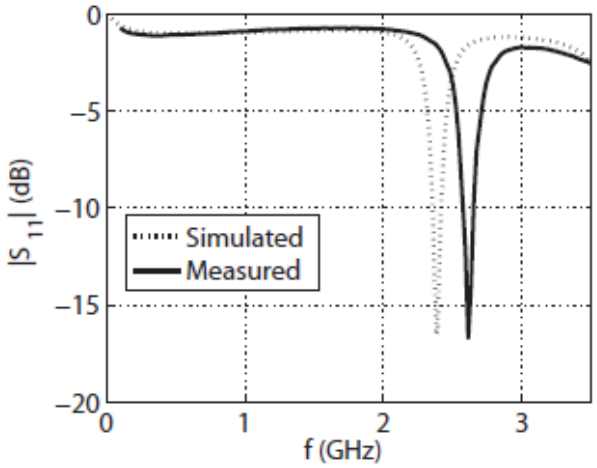
Photograph of the commercially available flexible graphene-based conducting material and (b) a photograph of the prototype (with dimensions) of the fabricated graphene-based patch antenna [4]



Graphene-based reconfigurable MP antenna [3]



The S_{11} for the ON state (fr=60GHz).



Measured and simulated S_{11} values of the prototype graphene-based antenna

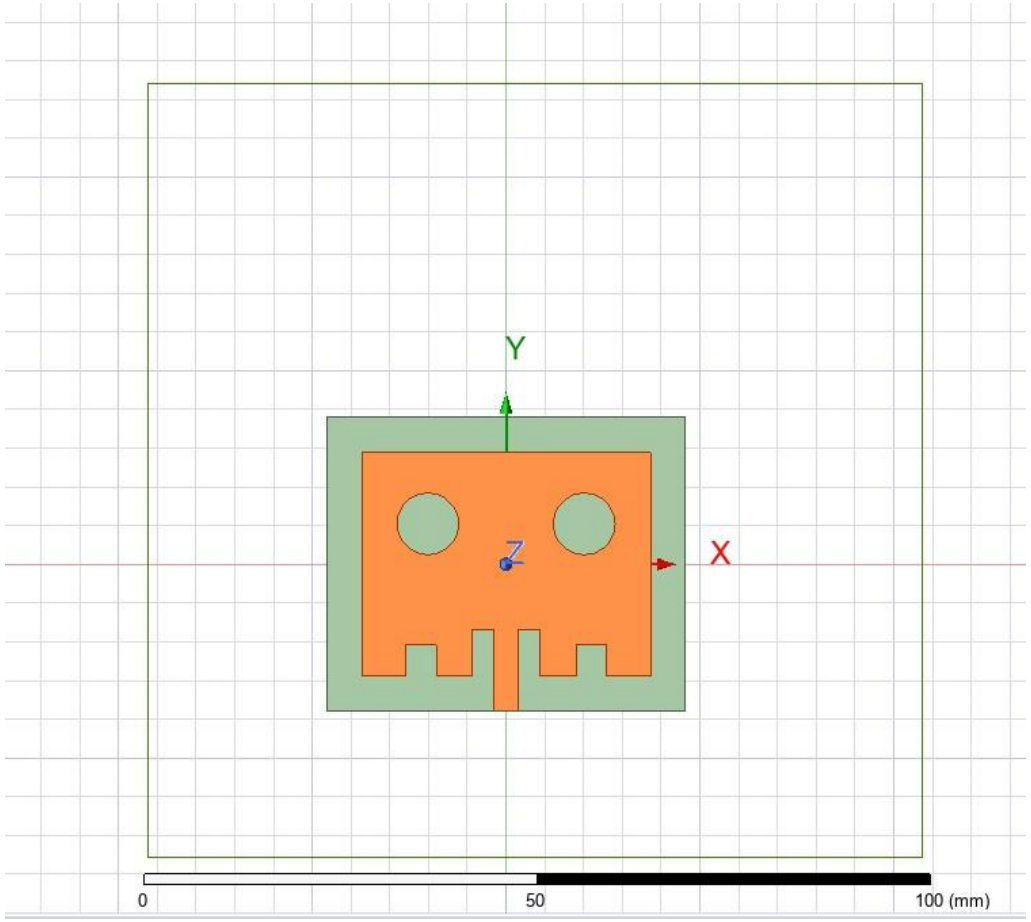
MPA Simulation

The design of the antenna is simulated using Ansys Twin Builder HFSS (High Frequency Structure Setup) design

Model design

- **A Microstrip feed line with an impedance of 50 Ohms is attached in the middle of the patch.**
- **To provide excitation, a lumped port with an impedance of 50 ohms was created to excite the antenna.**

Design parameter	Value
Resonating frequency	2.448 GHz
Relative permittivity	4.4
FR4 Substrate thickness	1.5 mm
Ground plane Length	46.26 mm
Ground plane breadth	37.87 mm
Patch Length	37.26 mm
Patch breadth	28.87 mm
Circular slot radius	4 mm
Feeder length	10.5 mm
Feeder breadth	3 mm
Square cut	4 mm

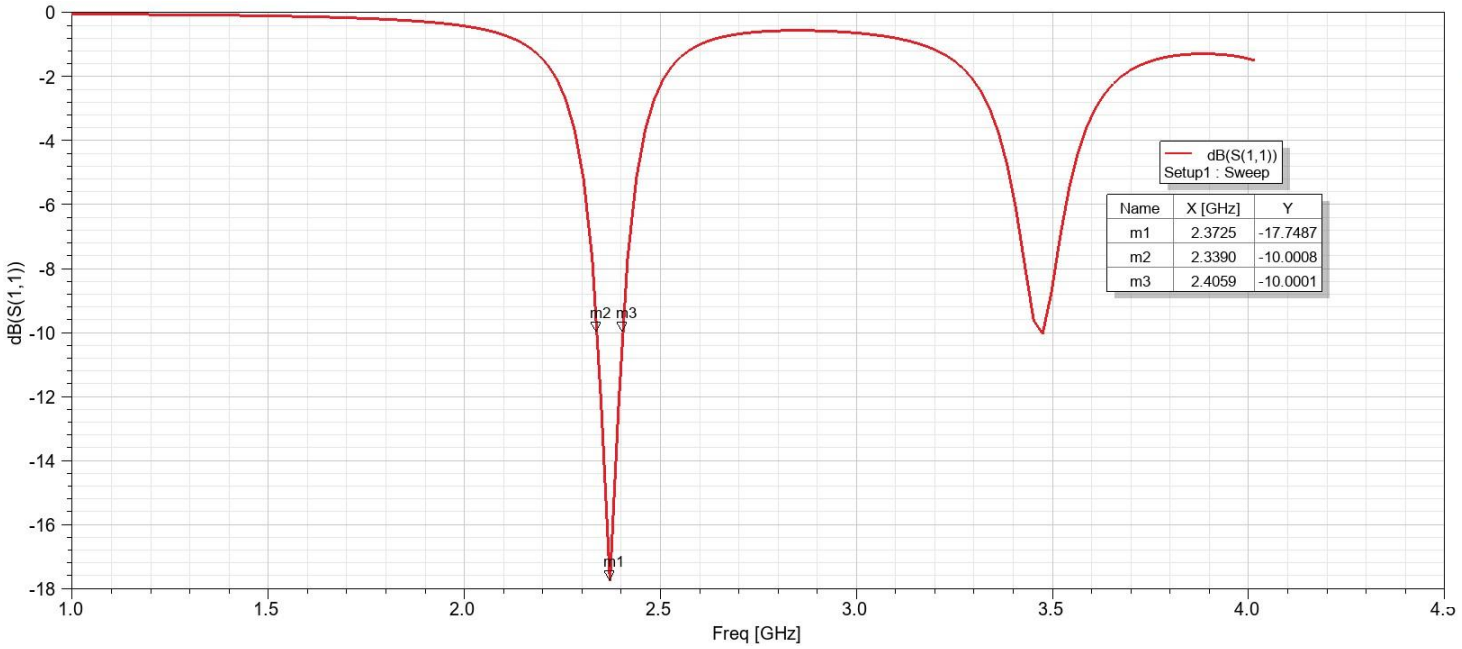


Designed MPA in HFSS with slots

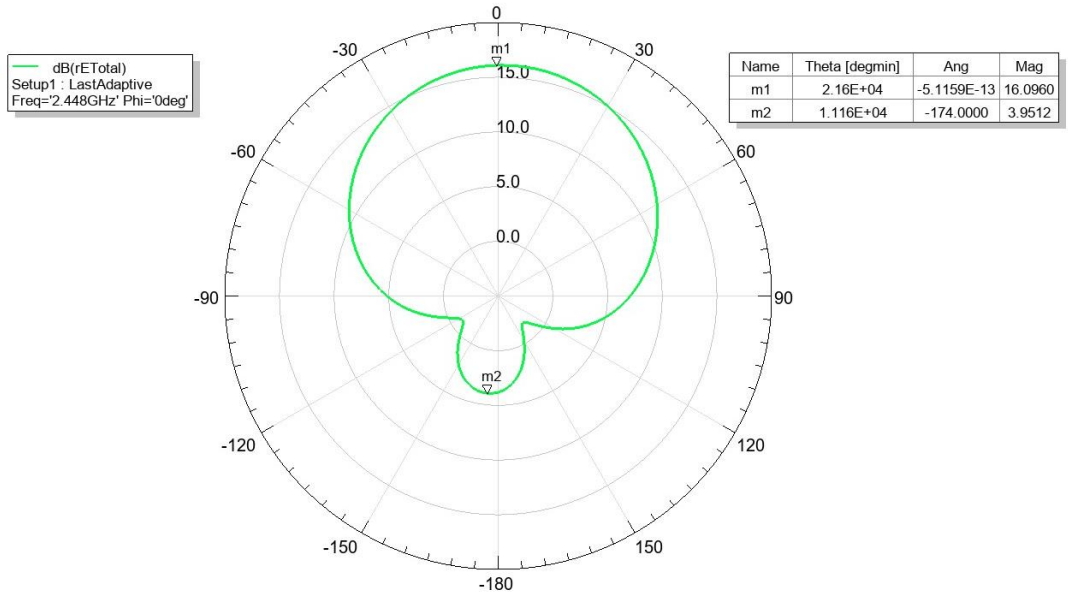
For validation and simulation, a frequency sweep range of 1GHz to 8GHz was defined.
A sweep is a range of frequencies for which all the parameters of the antenna are calculated

Simulation Results

S_{11} parameter analysis



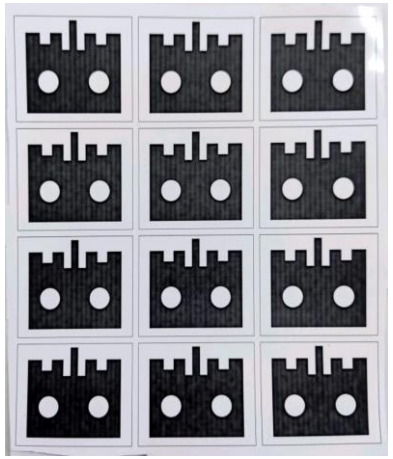
Radiation Pattern



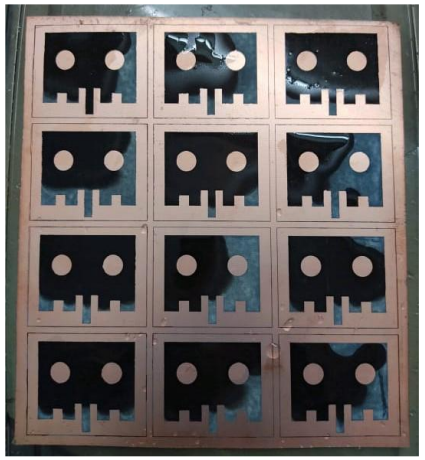
Antenna with circular slot:
The antenna demonstrates a return loss of -17.7487 dB at its resonant frequency of 2.3725 GHz, which signifies efficient power transmission and minimal signal loss.

At 2.448 GHz, the circular slotted microstrip patch antenna exhibits a well-defined main lobe with a peak radiation intensity of 16.09 dB and a back lobe level of 3.95 dB.

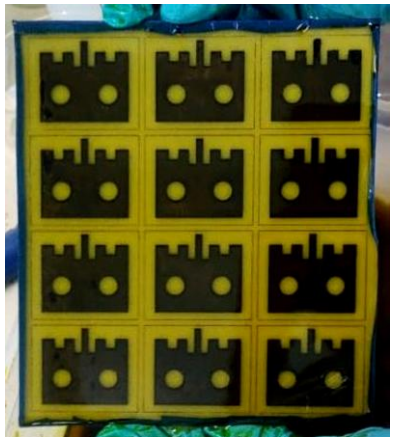
Fabrication of MPA



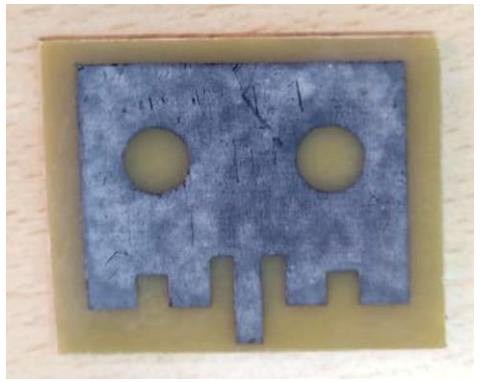
Printed MPA Design on Photopaper



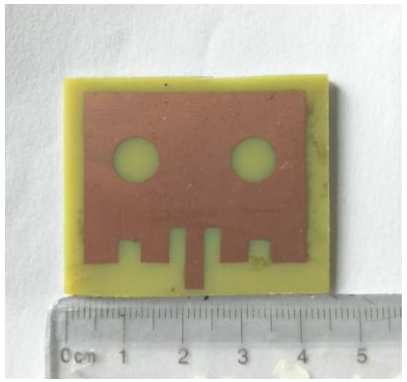
Pattern Transfer to the FR4-Cu Substrate



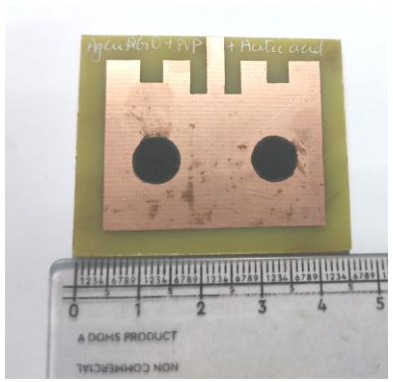
$FeCl_3$ Etched Substrate



Individual MPA Design on FR4 After Cutting



MPA Design After Removal of the ink

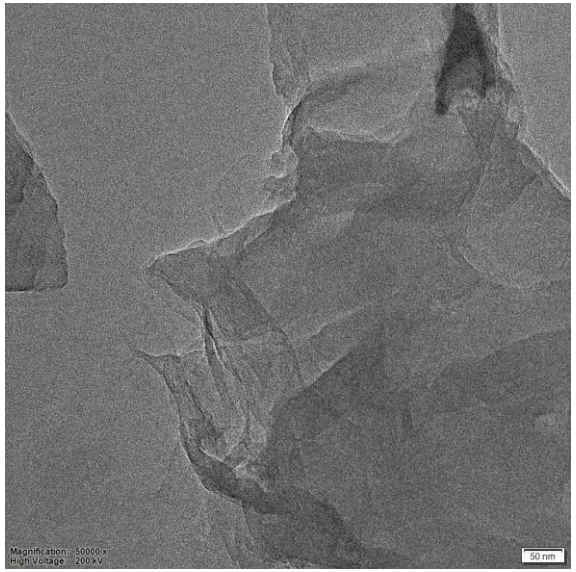


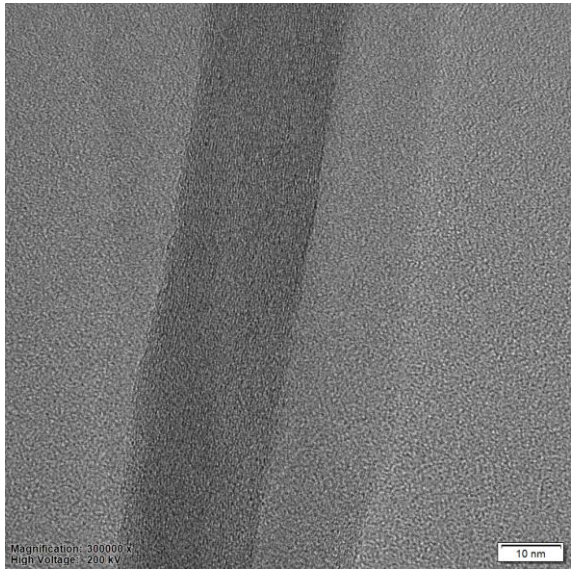
Nanomaterial Coated Circular Slotted MPA

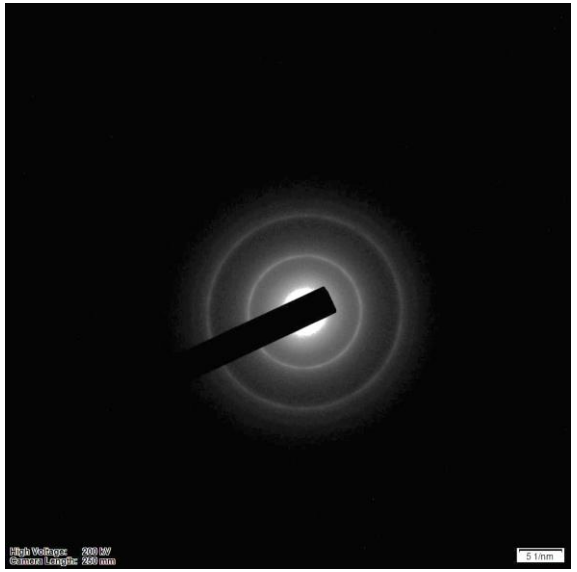
TEM Analysis

Nanomaterials

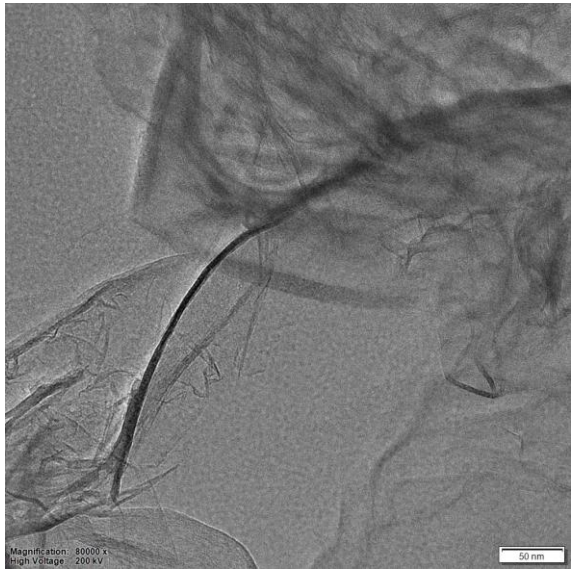
(a) RGO (b) No. of Layers (c) SAED Pattern



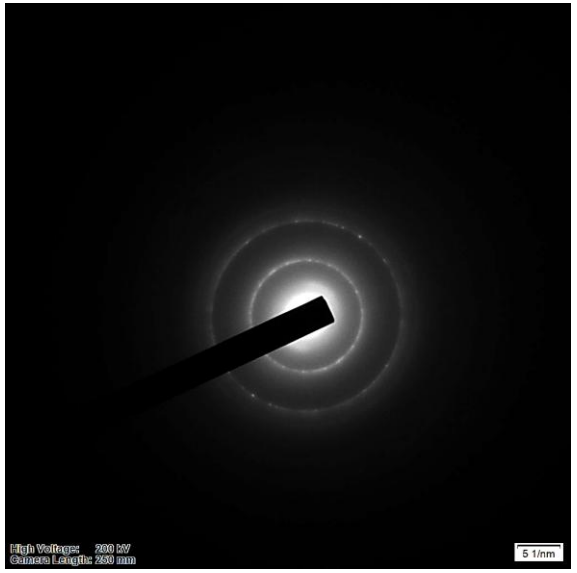




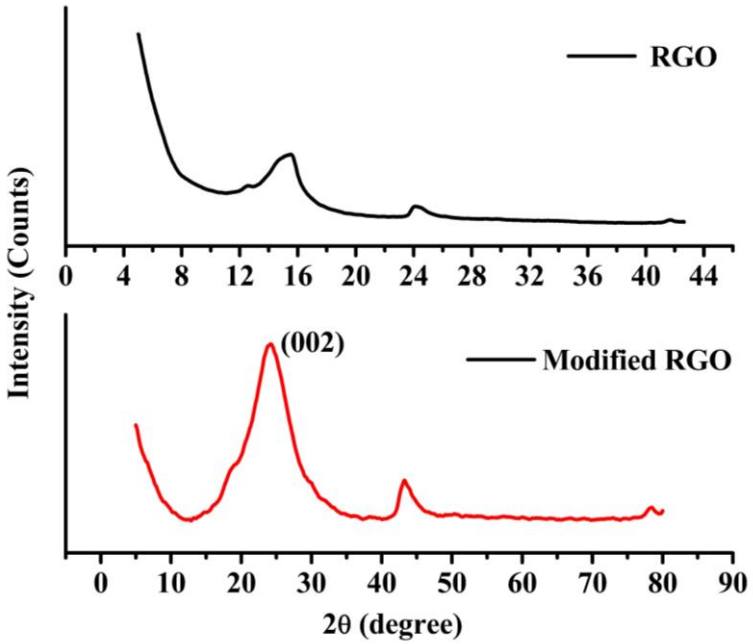
(a) H_2SO_4:HNO_3 Modified RGO (b) No. of Layers (c) SAED Pattern

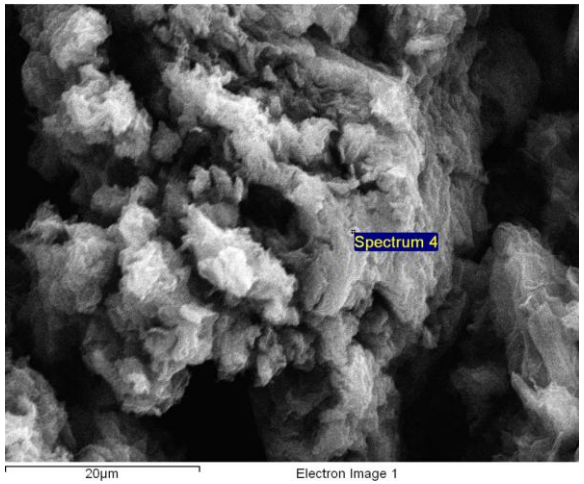


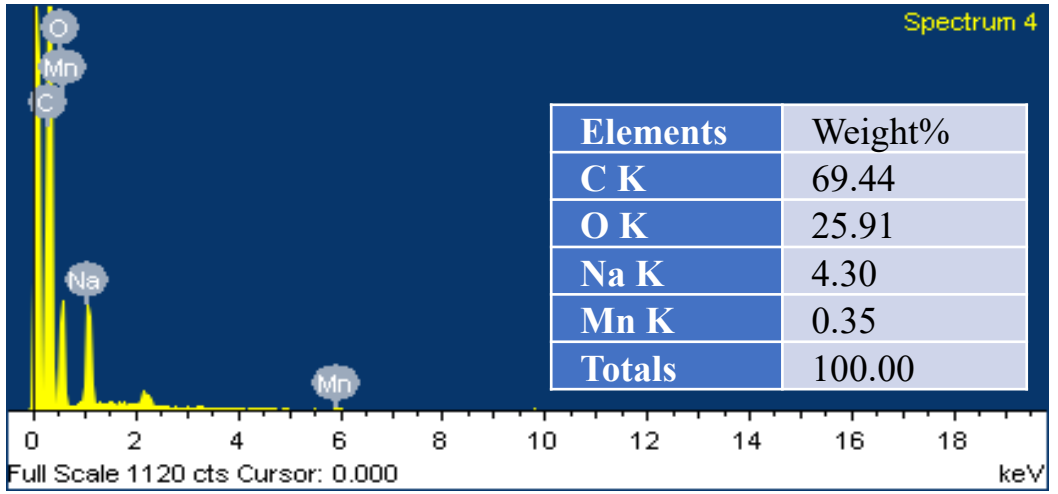




XRD and FESEM Analysis



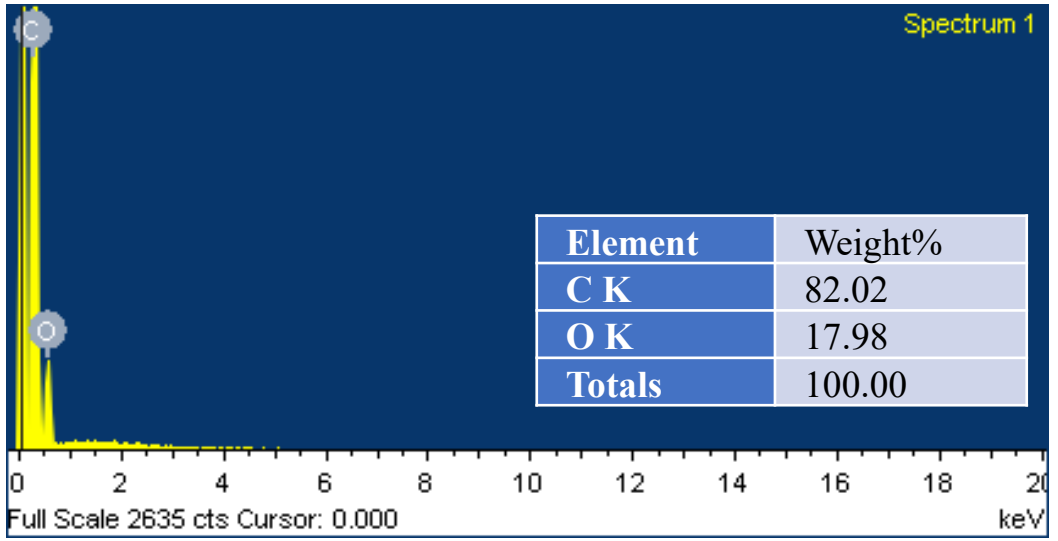




Elements	Weight%
C K	69.44
O K	25.91
Na K	4.30
Mn K	0.35
Totals	100.00

The EDS spectra revealed a higher percentage of carbon, and XRD peaks confirmed the efficient reduction

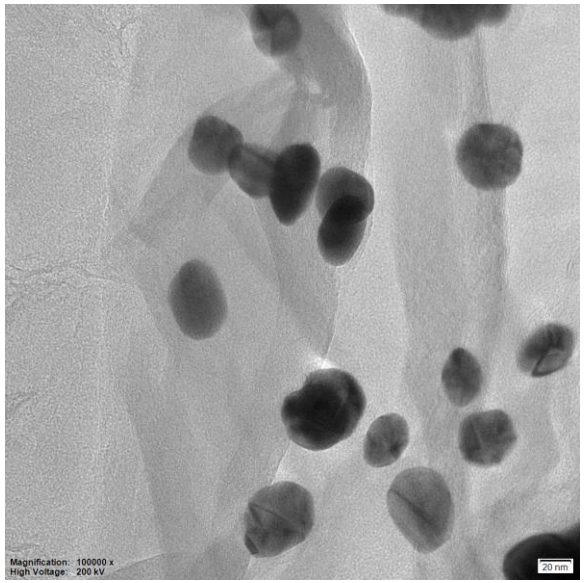


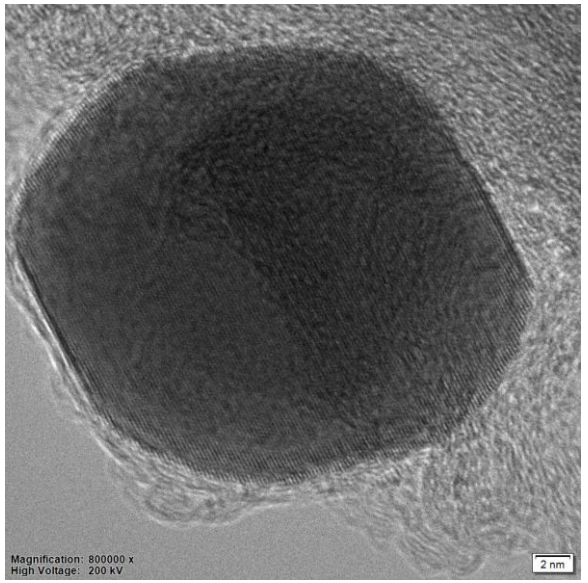


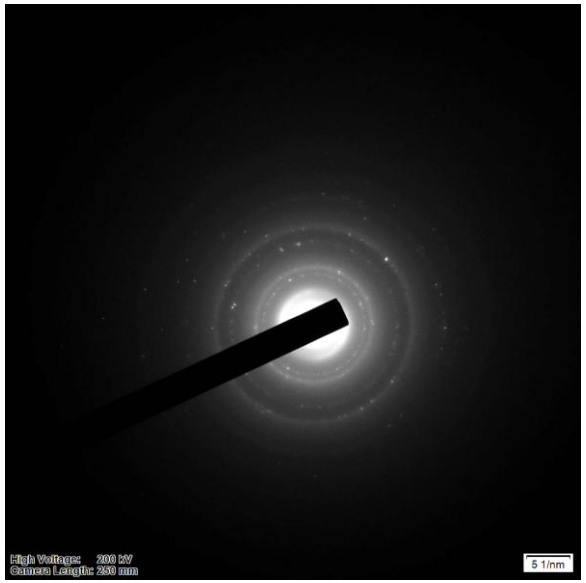
Element	Weight%
C K	82.02
O K	17.98
Totals	100.00

TEM Analysis

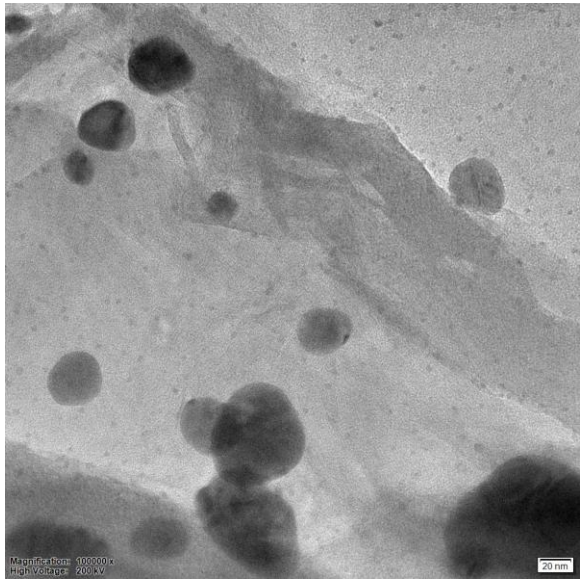
(a) Ag-RGO (b) HRTEM image (c) SAED Pattern

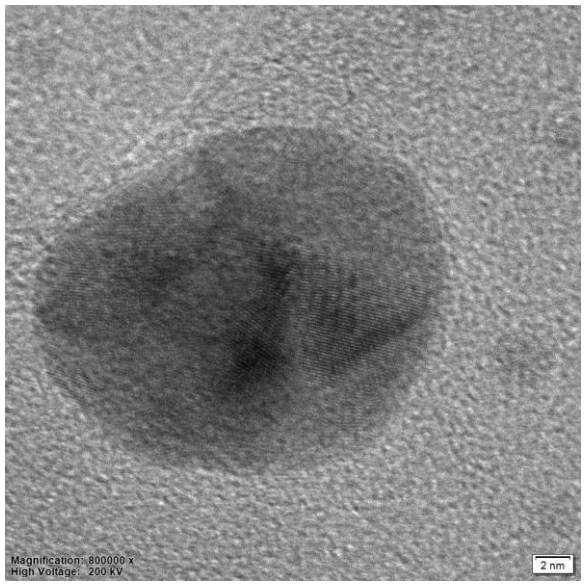


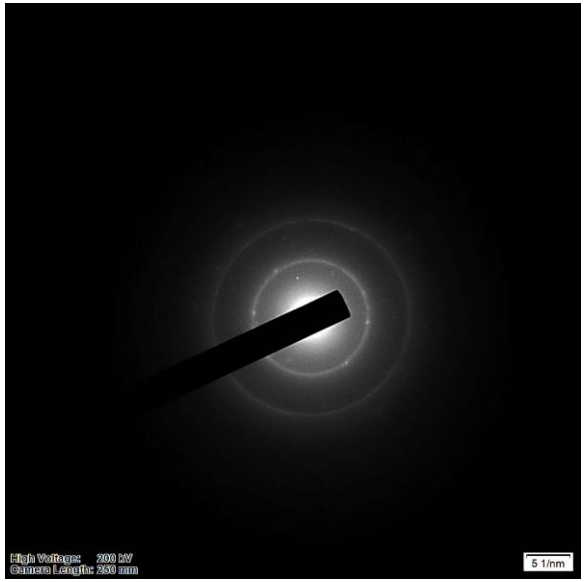




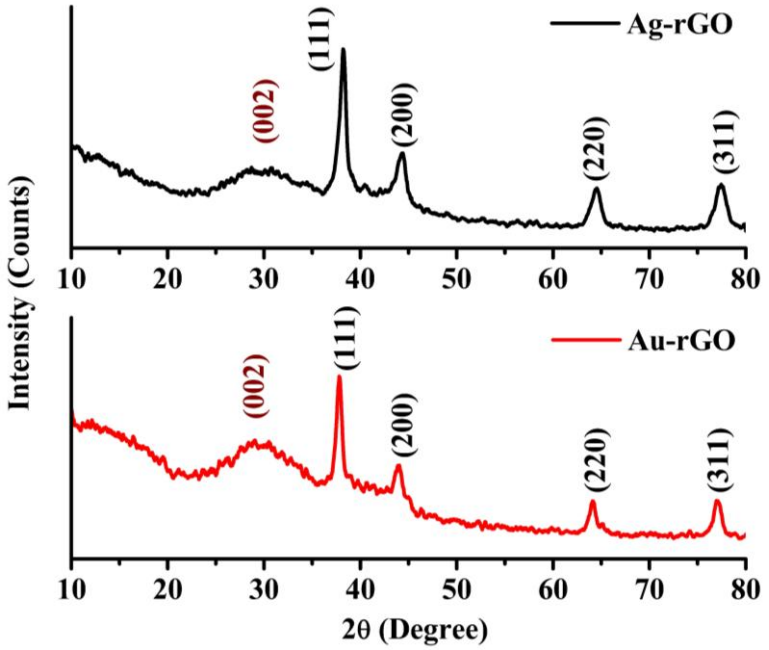
(a) Au-RGO (b) HRTEM image (b) SAED Pattern



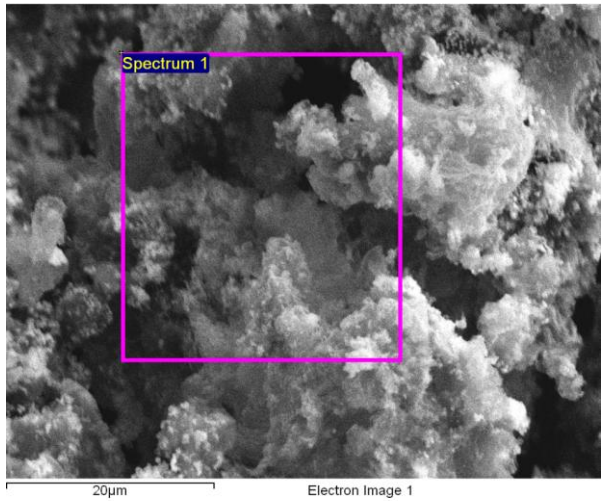


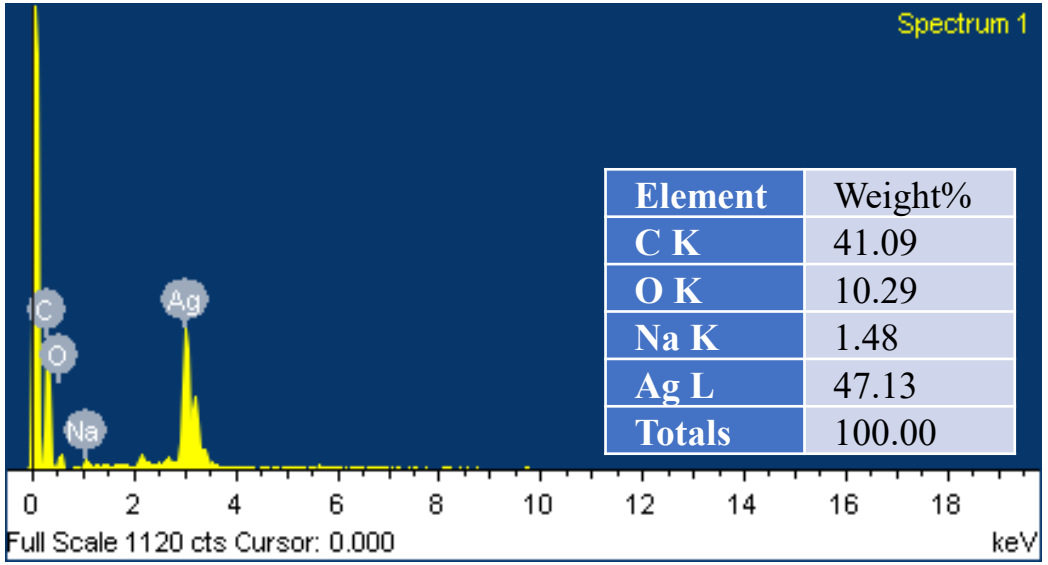


XRD and FESEM Analysis

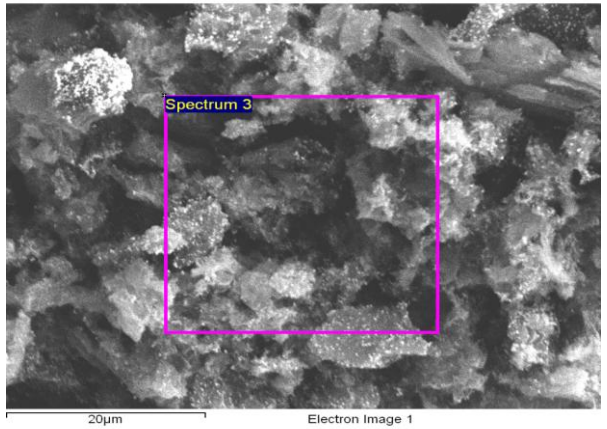


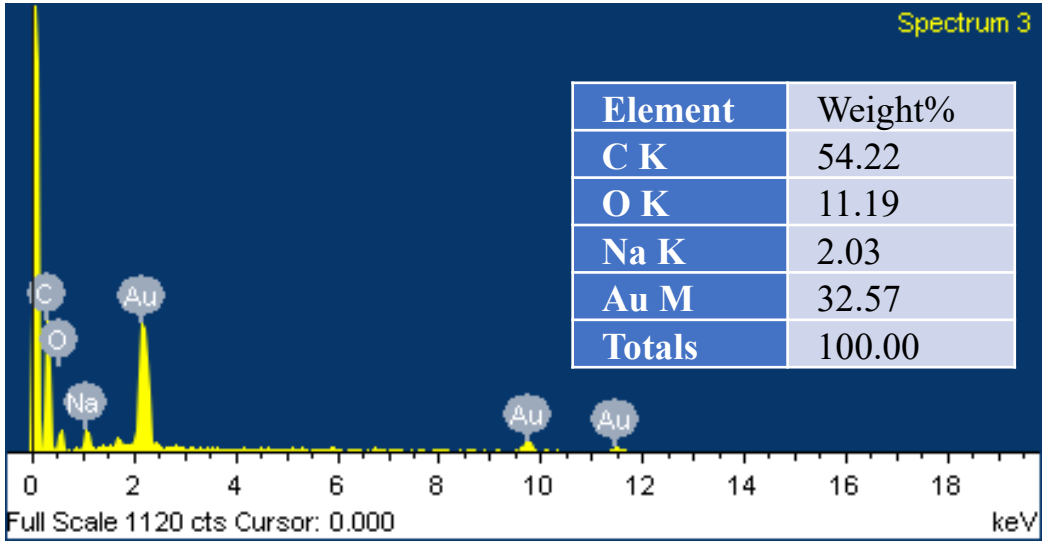
The EDS spectra revealed the elemental presence of carbon, Ag and Au. The XRD peaks confirmed the successful synthesis of Ag-RGO and Au-RGO nanocomposites decorated with Au and Ag nanoparticles (FCC).





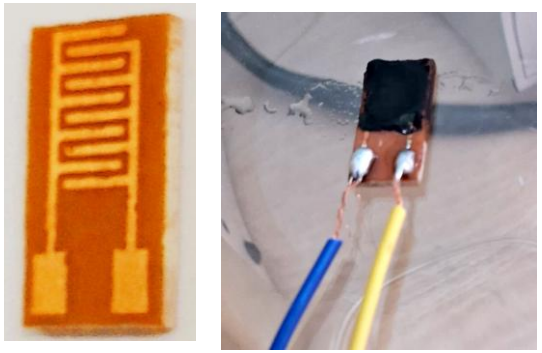
Element	Weight%
C K	41.09
O K	10.29
Na K	1.48
Ag L	47.13
Totals	100.00



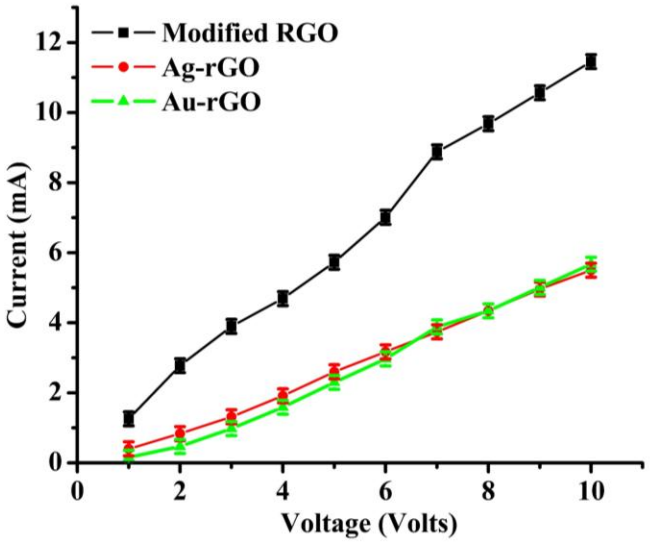


Element	Weight%
C K	54.22
O K	11.19
Na K	2.03
Au M	32.57
Totals	100.00

Experimental Results

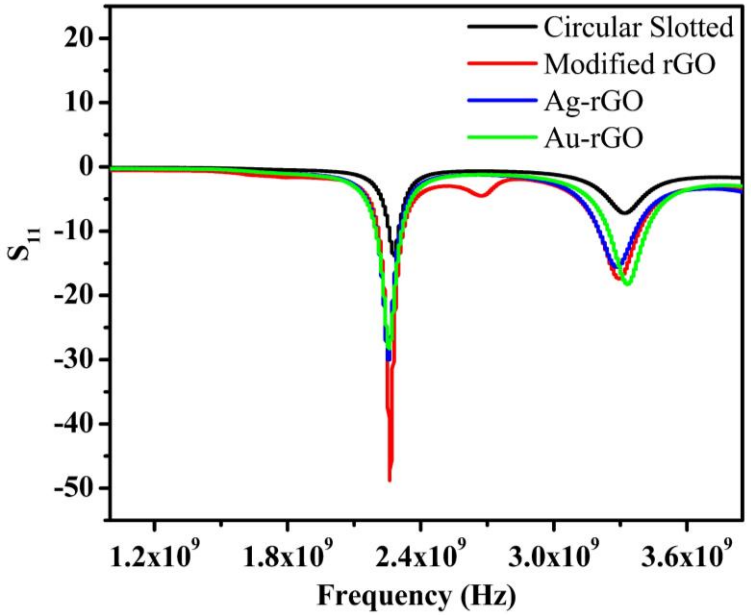


V-I measurement

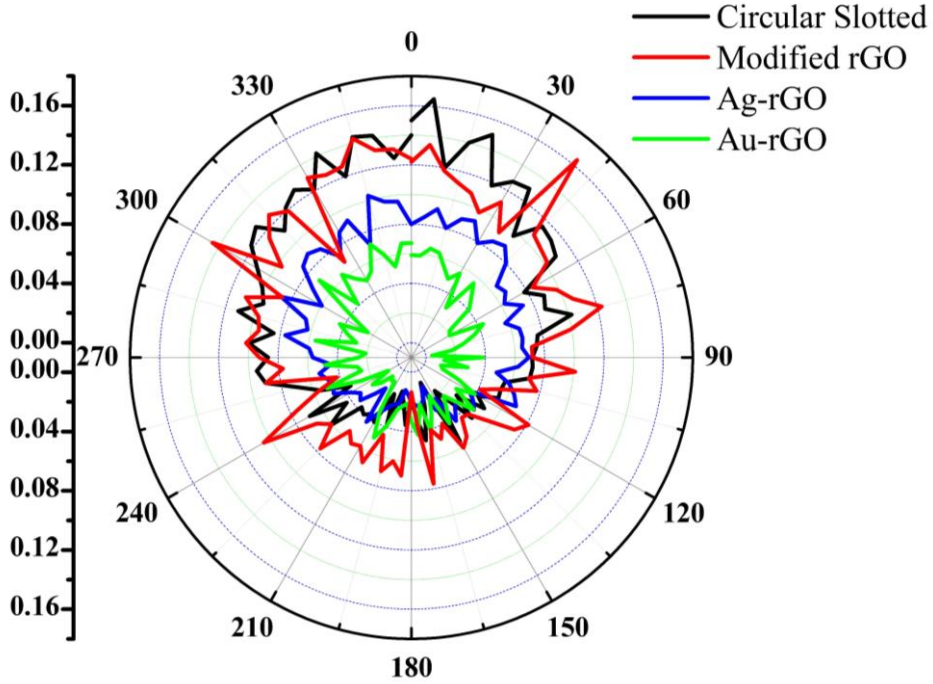




Experimental setup for Radiation Pattern



Sample	S_{11}	Bandwidth
Circular Slotted MPA (Empty)	-13.8 dB at 2.27 GHz	0.05 GHz
RGO deposited MPA	-48.8 dB at 2.25 GHz	0.1 GHz
Ag-RGO deposited MPA	-30 dB at 2.27 GHz	0.12 GHz
Au-RGO deposited MPA	-28.18 dB at 2.27 GHz	0.12 GHz



Conclusions

- ✓ The S11 parameter plot indicated a significant improvement in impedance matching for nanomaterials in the circular slots.
- ✓ Among the tested configurations, the rGO-based circular-slotted antenna achieved the best impedance matching, with a return loss of approximately –49 dB, which is 36 dB higher than that of the antenna without nanomaterials.
- ✓ Radiation pattern analysis reveals that the rGO-deposited circular slot MPA achieved the most significant gain improvement compared to other antenna configurations.

References

1. S. Mahmud, M. Jusoh, S. Jasim, A. Zamani, and M. Abdullah, “Design, simulation and analysis of a microstrip antenna using PU-EFB substrate,” in IOP Conference Series: Materials Science and Engineering, vol. 342, p. 012021, IOP Publishing, 2018.
2. S. Didde and R. Dubey, “Sol–gel derived ceramic nanoparticles as an alternative material for microstrip patch antenna in WLAN applications,” Scientific Reports, vol. 14, no. 1, p. 13684, 2024.
3. Saif Ali Mahdi Alwazzan, Ali Abdullah Khamees, and Mustafa Al-Rubaye. “Designing and Simulating a Tunable Microstrip Patch Antenna for 5G Communications Utilising Graphene Material,” Journal of Communications vol. 17, no. 4, April 2022.
4. Sayeed Z. Sajal; Benjamin D. Braaten; Val R. Marinov. “A microstrip patch antenna manufactured with flexible graphene-based conducting material,” 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting.