Fused Deposition Modeling 3D printed metasurfaces for microwave applications

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Outline

- Introduction to 3D printing / FDM
- Fabrication and characterization of the elementary SRR unit
- Sensing application
- Harvesting application
3D printing process

- Any process in which a material is joined or solidified under computer control to create a 3 dimensional object.

Novel technique of building 3 dimensional structures, made from polymer materials, polymer composites.

4 different types of 3D printing techniques

Construction of 3D polymer structures becomes rather easy by employing the 3D printing technology
Fused Deposition Modeling 3D printing process:

FDM advantages:
- Quick
- Low cost
- No chemicals are needed
- Ideal for 3D printing of polymers.
- Large samples

Disadvantages:
- Only polymers can be used
- Extruder Jams

Electromagnetic Metamaterials and Metasurfaces
Metamaterials are artificial structures with periodic subwavelength features, which collectively behave as materials with effective new properties, e.g. $\varepsilon_r$ and/or $\mu_r$.

- **Meta-atom**: Elementary “unit-cell”
- **Metasurface**: 2D “sheet” metamaterial, typically thin planar layered composite

The modification of the metasurface local resonance provides the means of achieving exotic functions:

- band-pass/stop filters,
- perfect absorbers,
- polarizers,
- leaky-wave antennas,
- flat lenses

*S.B. Glybovski et al. / Physics Reports 634 (2016)*
Metamaterials/Metasurfaces Overview

K. Meng, Optics Express 16 (27), 2019

G. Kenanakis, Optical Materials Express 2 (12), 1702-1712, 2012

C.M. Soukoulis, Science 330, 1633, 2010

A.C. Tasolamprou, PRB 94 (20), 2016.

A.C. Tasolamprou, IEEE access 7, 122931-122948, 2019

sensing

chiral

mm-scaled software defined
Metamaterials/Metasurfaces for the microwave spectrum

Every-day life use electronics
- Antennas
- Waveguides
- Filters
- Modulators
- Sensors
- Harvesters
and many more....
**Principles of SRR e/m response**

- The electric response in a SRR type of metamaterial is a result of the coupling of the electric field with the wire-type modes.

- The magnetic response in a SRR type of metamaterial is a result of the coupling of the impinging waves and the infinite magnetic dipoles generated by the circulation of alternating currents.
Conducting polymer composites (commercial) Polymer + conductive paint

FDM printing process

Effective mm units

Potential advantages:

1. Quick and easy production
2. Large scale production
Commercially available polymer composites: *No need to produce our own ones*

- Acrylonitrile Butadiene Styrene (ABS) (Makerbot Industries)
- ABS with carbon nanotubes 1% w/w (3DXTECH)
- Polylactic Acid (PLA) + graphite 20% w/w (CON-PLA) (Proto Pasta)
- PLA + graphene 15% w/w (CON-GRA) (BlackMagic 3D)
Experimental Details: Samples Produced

Filaments:

- Polylactic acid (PLA) filament painted over with conductive silver epoxy.
- Commercially available filament known as Electrify. A Polyvinylidene chloride (PVDC) matrix, in which copper (Cu) nanoparticles are included in a weight ratio 20% thus the electrical transport properties.
Experimental Details: Samples Produced

**Samples in the mm**

![Diagram of 3D printing process]

**Deviation between design and fabrication**

**Table I**

<table>
<thead>
<tr>
<th>Printing Conditions</th>
<th>PLA</th>
<th>Electrify</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament Diameter</td>
<td>1.75 mm</td>
<td>1.75 mm</td>
</tr>
<tr>
<td>Filament Conductivity</td>
<td>0</td>
<td>$10^4$ S/m</td>
</tr>
<tr>
<td>Nozzle Diameter</td>
<td>0.4 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Nozzle Temperature</td>
<td>230°C</td>
<td>140°C</td>
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<tr>
<td>Printing bed temperature</td>
<td>110°C</td>
<td>Room temperature</td>
</tr>
<tr>
<td>Printing speed</td>
<td>25 mm/sec</td>
<td>15 mm/sec</td>
</tr>
</tbody>
</table>

**Graph**

![Graph showing measured vs nominal values]
Experimental Details: Characterization

- Sharper resonances
- Lower frequencies

- Lower Q factor
- Higher frequencies
Experimental Details: Characterization

PLA with silver paste

Electrifi

Characterization of the geometrical parameters effect on the metasurface response
Experimental Details: Sensing Function

- A droplet of polysterene (PS), diluted in toluene
- The toluene is evaporated, the PS is solidified into the SRR gap

✓ The resonance shifts
Flexible 3D Printed Conductive Metamaterial Units for Electromagnetic Applications in Microwaves

by Anna C. Tasolamprou 1,*, Despoina Mentzaki 1,2, Zacharias Viskadourakis 1, Eleftherios N. Economou 1,3, Maria Kafesaki 1,2 and George Kenanakis 1

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Conclusion

- Cost-effective, eco-friendly and accessible method
- Ultralight and flexible millimeter-scale metasurfaces using a household 3D printer
- Well defined resonances dependent on the geometrical parameters/infiltrating dielectric materials similar to those obtained for traditional PCB
- Electromagnetic components and fabrics for coating a plethora of devices and infrastructure units of different shapes and size.
Publications on 3D printing

Electromagnetic shielding effectiveness of 3D printed polymer composites

Z. Viskadourakis, K. C. Vasilopoulos, E. N. Economou, C. M. Soukoulis, and G. Kenanakis


Electromagnetic shielding effectiveness and mechanical properties of graphite-based polymeric films


Transport properties of 3D printed polymer nanocomposites for potential thermoelectric applications

Z. Viskadourakis, G. Perrakis, E. Symeon, J. Giapintzakis, and G. Kenanakis


3D structured nanocomposites by FDM process: a novel approach for large-scale photocatalytic applications

Z. Viskadourakis, M. Sevasti, and G. Kenanakis


3D printed graphene-based electrodes with high electrochemical performance

D. Vernardou, K. C. Vasilopoulos, and G. Kenanakis


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