# Towards Additive Manufacturing of Dielectric Accelerating Structures

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## Abstract

Additive Manufacturing techniques such as stereolithography have developed rapidly in the last decade and provide the ability to simplify prototyping of unique, complex structures. For the application to dielectric accelerating structures a precise knowledge of the dielectric permittivity of the material is essential to the design. Here we present the characterization of commercially available polymers used in stereolithographic manufacturing by means of refractive index and absorption in the frequency range from 220 GHz to 330 GHz, and around 60 GHz. Vacuum compatibility has been tested with respect to achievable pressure level and residual gas mass spectra. In the future the polymer properties will be applied to coupler designs for terahertz-driven dielectric accelerator components.


## Vacuum tests

- *FormLabs High Temperature Resin* tested in RGA with prior temperature treatment
- Up to 100h pump down
- Mass spectrum analyzed after 24h

| Temp. treatment | pressure [mbar] @ 48h |
|---|---|
| 90 min @ 235°C | 1e-7 @ 24h |
| 180 min @ 235°C | 4e-8 |
| 360 min @ 235°C | 6e-8 |
| 297 min @ 175°C, rough vacuum | 2e-8 |
| 297 min @ 175°C, nitrogen environment | 6e-8 |

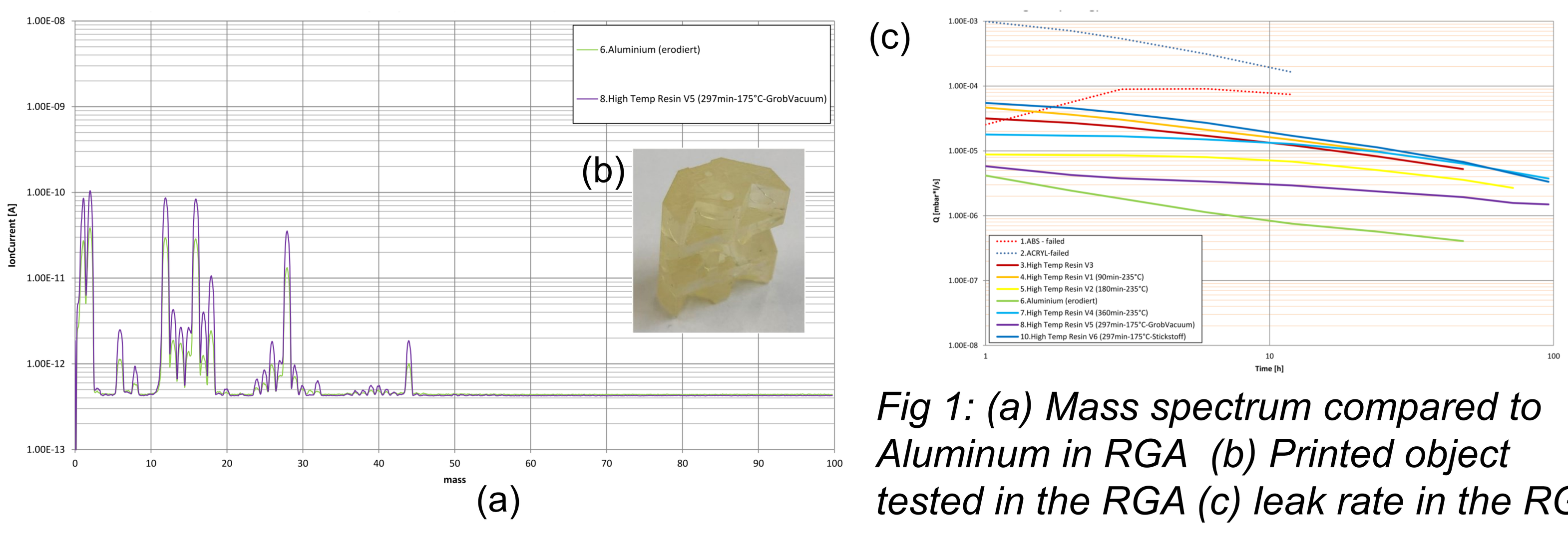


*Fig 1: (a) Mass spectrum compared to Aluminum in RGA (b) Printed object tested in the RGA (c) leak rate in the RGA*

## Dielectric Properties

### Experimental Setup for 60 GHz

Applied Methods:
- Angular deflection at a prism due to Snell's law for determining the refractive index $n$
- Absorption index $k$ from attenuation through a slab for various thicknesses

Experimental Parameters
- Materials under test: ***FormLabs Clear Resin, FormLabs High Temperature Resin***
- Two prismatic samples each, with $\gamma = 30°$ and $\gamma = 60°$
- 46 Angular scans of 60°
- Three *1cm* thick flat samples, stacked

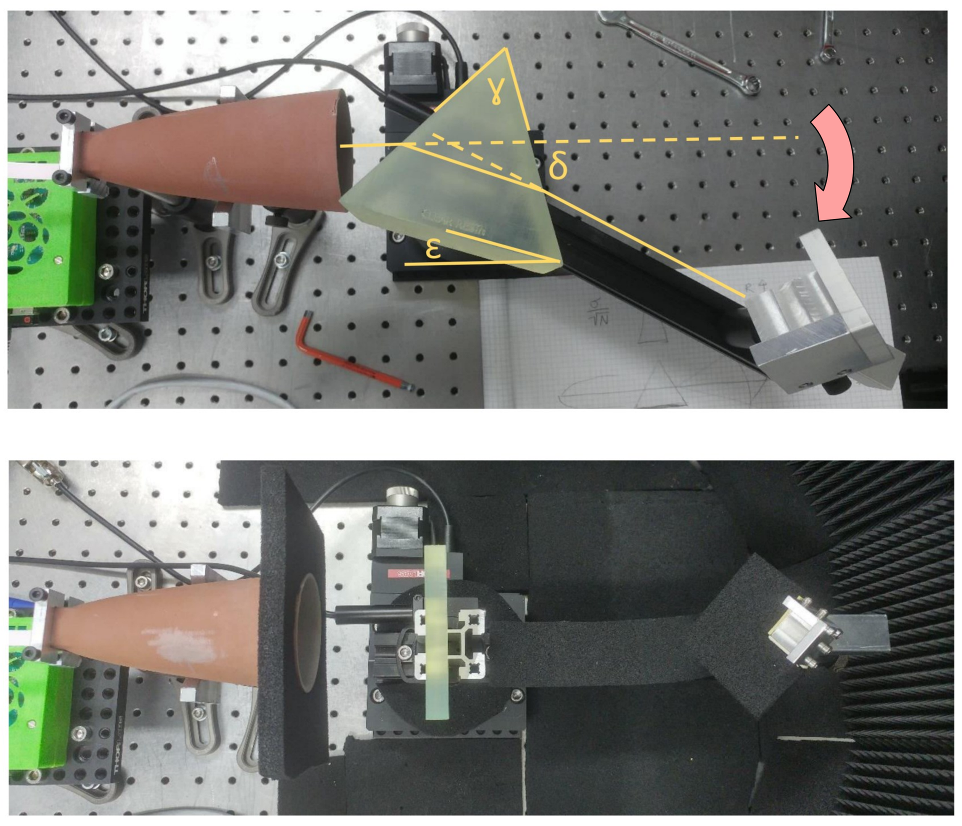


*Fig 2: a) Experimental Setup for measuring the real part of the refractive index via an angular scan b) Setup for attenuation measurements on slabs of different thicknesses*

### Results

| | Refractive Index | Absorption |
|---|---|---|
| Clear Resin | 1.60 ± 0.024 | < 0.04 db/cm |
| High Temperature Resin | 1.64 ± 0.036 | < 0.04 db/cm |

### Experimental Setup at 275 GHz

Applied methods:
- Quasi Gaussian optical setup for free space measurement of S-parameters
- Nicolson-Ross-Weir method [1] to extract complex material properties
- Transmission only iterative method using Newton algorithm on error function [2]
- PTFE Sample for reference measurements
  - $d = (6.38 \pm 0.01)\ mm, \epsilon_r = 2.0695 - i\ 1.3 \times 10^{-3}$ [3]

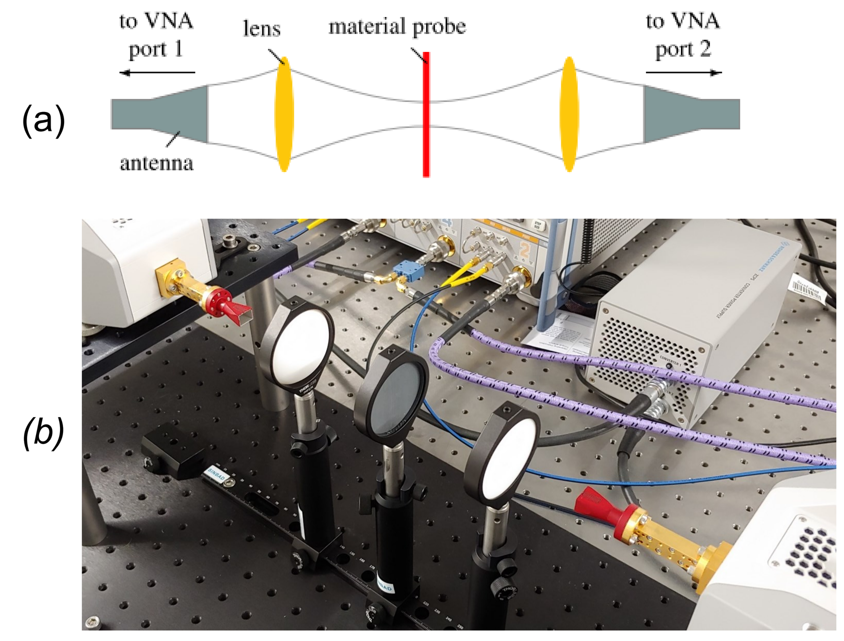


*Fig 3: a) Sketch of the Quasi-Gaussian setup [1] b) Corresponding experimental setup*

### Calibration Techniques

- Two tier Calibration:
  - TOSM at waveguide ports
  - Free Space calibration
- Free Space: Shift reference plane, remove systematic errors
  - Line-Network-Network (LNN) [4]
  - Thru-Reflect combined with Time Gating [2]

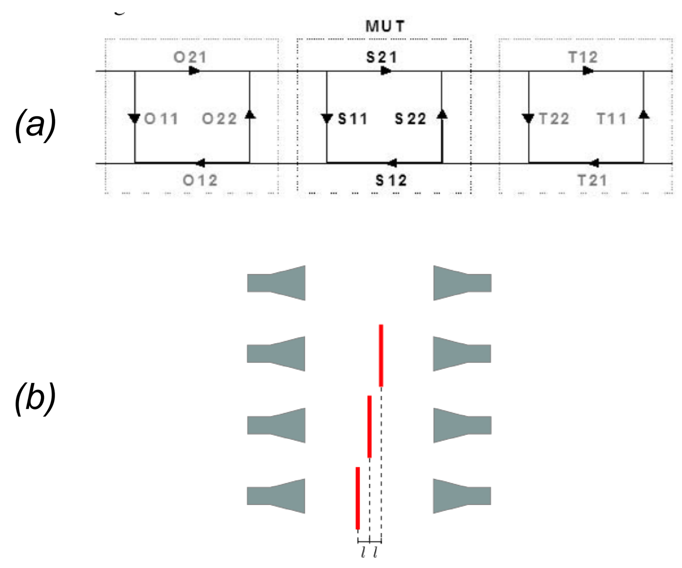


*Fig 4: a) Signal Flow Graph of the error model b) Setup of LNN self-calibration [4]*

### Results

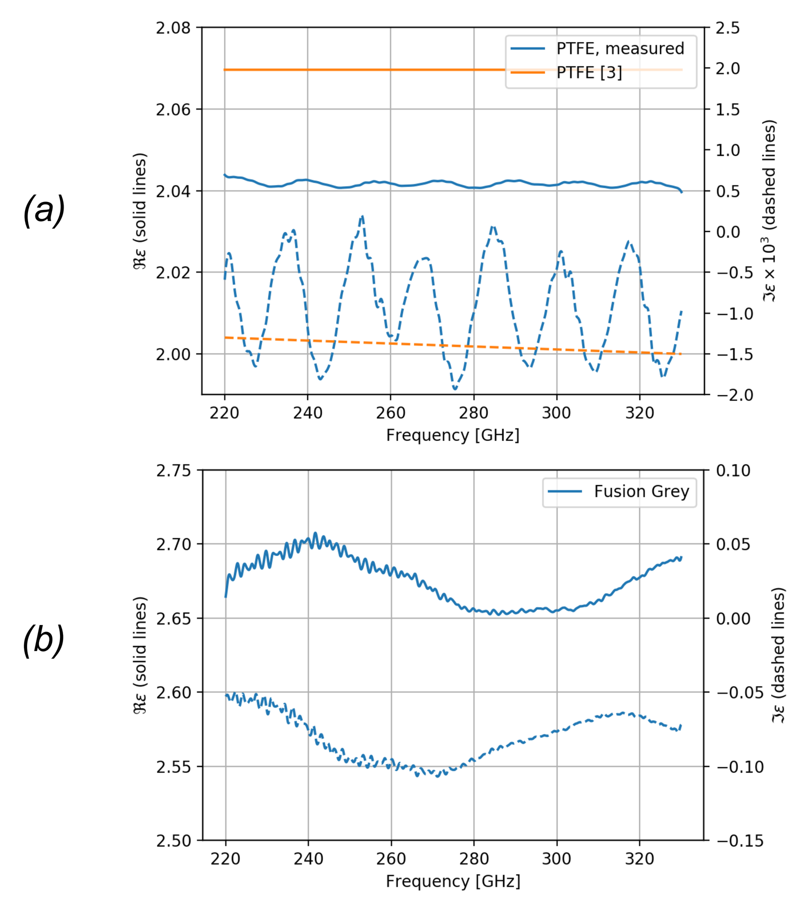


*Fig 5: Complex $\epsilon_r$ of a) PTFE and b) Asiga FusionGrey from 220 GHz – 330 GHz*

- Material under Test: ***FusionGrey***
- Higher real permittivity as PTFE
- Two orders of magnitude higher absorption, $k_{PTFE} = 0.5 \times 10^{-3}, k_{FusionGrey} \approx 0.02$

## Discussion

- Vacuum tests appear to be promising for UHV applications
- The refractive index at 60 GHz is the same for both FormLabs resins within the uncertainty of the measurement. For the absorption only an upper limit could be determined. Fresnel reflections at the slab lead to systematic errors.
- The measured $\epsilon_r$ of PTFE from 220 GHz to 330 GHz was ≈2% below the literature value. This deviation could originate from the roughness of the slab's surface. The imaginary part of $\epsilon_r$ was on the same order of magnitude as the literature value but varied by more than 100%. Thicker samples must be tested for reliable absorption measurements
- The FusionGrey sample has a much higher refractive index than PTFE, but also two orders of magnitude higher absorption.
- The oscillations in $\epsilon_r(f)$ can be attributed to misalignment, diffraction on the samples and insufficient fulfillment of the far-field conditions.

## Outlook

- The Quasi-Gaussian optics setup will be improved with respect to the spot size on the sample and the far-field condition
- The FormLabs High Temperature resin will be studied in the 300 GHz range
- Additional resins will be examined in order to compare the applicability for terahertz optics, couplers and waveguides
- New designs for free space to waveguide coupling will be studied
- Resistance to high power THz induced damage is an open question

## References


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**Acknowledgements**
This work has been supported in part by the Gordon and Betty Moore Foundation through the ACHIP program and by the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013)/ERC Grant Agreement n. 609920.