Microwave and mm-Wave characterization of treated copper foils with dielectric resonator method for efficient PCB development

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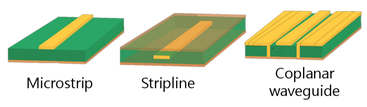
In this study a dielectric resonator device for direct characterization of treated copper foils at 40 and 62 GHz is developed. High sensitivity of the device facilitates distinction of even small conductivity variations between various foils. New, high frequency device, together with lower frequency units, are applied to investigate correlation between various copper foil treatments and effective conductivity within wide frequency from 13 to 62 GHz. Direct conductivity measurements with dielectric resonator devices allow for easy and accurate assessment of conductor losses of treated copper foils, eliminating necessity of building test vehicles.

Motivation for Conductivity testing

- Various sources of losses in electronic circuits (e.g. dielectric, conductor)
- Each source of losses contributes to intrinsic losses at a different level
- Precise direct methods for Dk/Df testing
- Indirect methods for conductivity testing
  - time consuming and expensive
  - implicit problem (e.g. connectors)

Insertion loss measurement process

Different boards designs can be used:



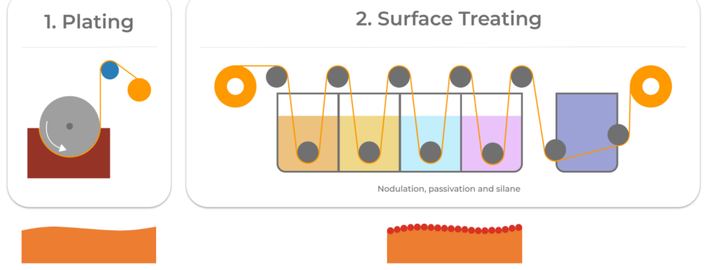
Foil production
Plating – treater-slitting-sheeting
Quality control
Shipment
1-2 weeks

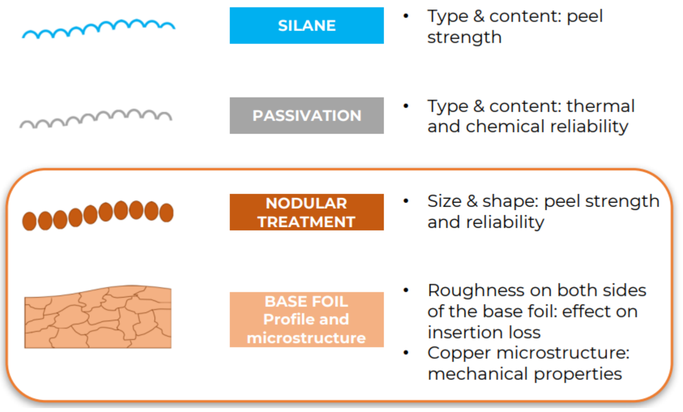
Board manufacturing
Production
Quality control
Shipment
1 month

Insertion Loss measurements
1 week

- Total lead time: around 2 months
- Cost per sample: up to 300€

Copper foil fabrication process overview



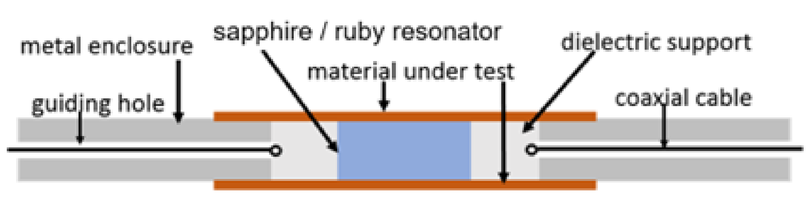


- Understanding relative contribution of each of the process parameter to signal loss (conductivity value) is the key for development of the next generation copper foils
- Shortening testing time is crucial also for electronic circuit designers and “time-to-market” for their products

- ✓ Direct characterization methods are more efficient
- ✓ Direct and fast information on treatment impact
- ✓ Direct methods provide explicit conductivity value
- ✓ Conductivity vs frequency = comprehensive information

Dielectric Resonator method

Concept of the Dielectric Resonator fixture for conductivity measurements

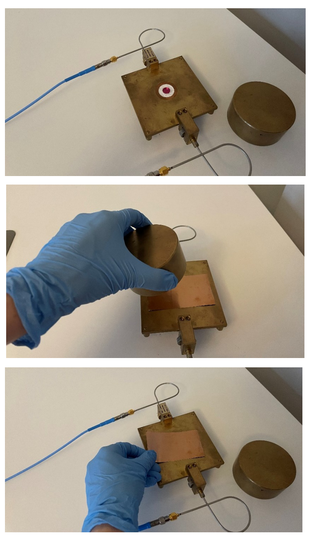


- Based on low-loss dielectric resonator (high Dk materials for low frequencies)
- Test samples form top & bottom cover of metal enclosure
- Dual-frequency method
- Measured Q-factor is translated into electric parameters

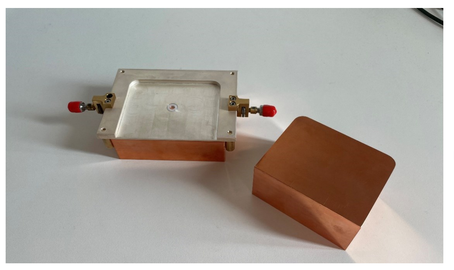
$$Q^{-1} = Q_c^{-1} + Q_p^{-1} = R_s/G_b + Q_p^{-1}$$

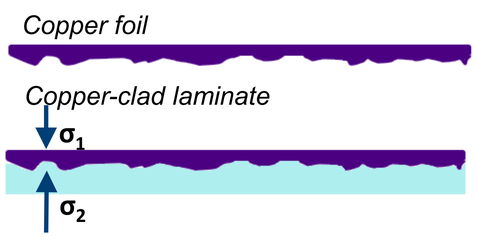
$$R_s = \left(\frac{\omega\mu_0}{2\sigma}\right)^{1/2}$$

14/20.4 GHz Ruby Dielectric Resonator Reference fixture



High frequency DR fixtures



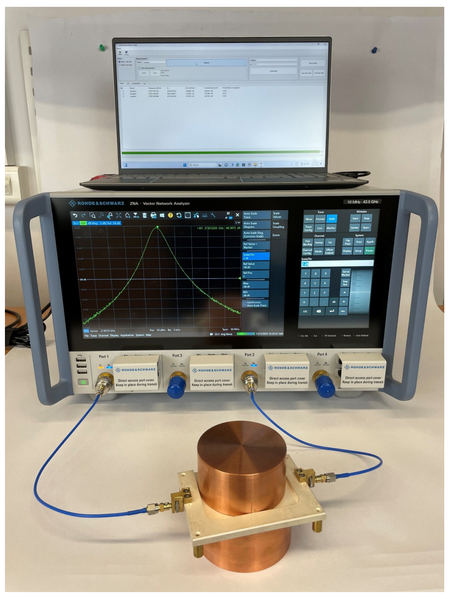


- 40/62 GHz Dielectric Resonator is proposed
- New mechanical design improves measurement repeatability
- For free-standing copper foil and copper-clad laminates
- New mechanical design introduced to 28/44 GHz Dielectric Resonator
- Minimum sample size 10 x 10 mm
- Software-controlled measurement procedure

Results and discussion

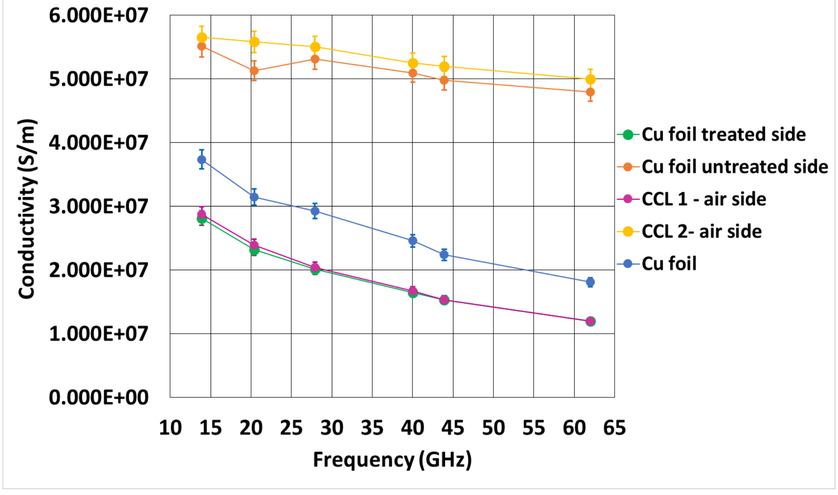
40/62 GHz DR fixture

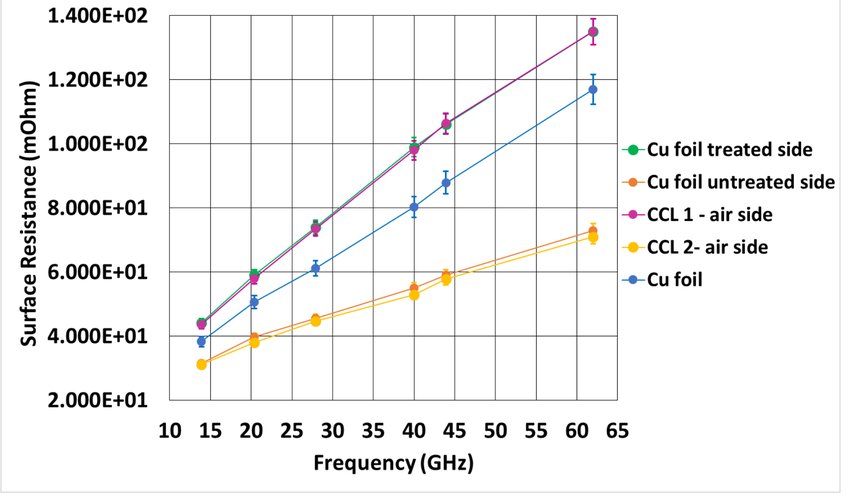
- Conductivity range: σ= 10^5 – 6×10^7 S/m
- Accuracy: ±2%
- Repeatability: @ 40 GHz σ < 0.5%, Rs < 0.2%
  @ 62 GHz σ < 0.5%, Rs < 0.2%



Measurement setup with DR 28/44GHz

Measurement results for free-standing and copper-clad laminates





- Reliable agreement between conductivity values measured with new and reference DR fixtures
- Common mechanical design allows for accommodating the same test samples in multiple fixtures
- Three fixtures enable conductivity testing in 14 – 62 GHz range – reliable information on frequency dependence of effective conductivity
- 25 x 25 mm test samples are sufficient for 14 – 62 GHz effective conductivity testing
- **Fixtures applicable for other conductors: silver pastes, bulk conductors, etc.**

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