

High-Frequency, Over-Temperature Measurements

Recent advances in thermal probing equipment have dramatically reduced the cost of obtaining temperature-dependent S-parameter data, while increasing throughput capabilities. These advances make thermal device modeling and process characterization both practical and affordable. The extreme temperature range of interest (-65° C to +200° C), however, increases the complexity of the calibration and measurement considerations.

General Extraction Method

The most common extraction methods for temperature and bias-dependent device modeling utilize cold-FET, pinched-FET, and hot-FET S-parameter measurements performed under bias conditions. Recent studies suggest that such measurements uniquely determine the device ECPs (equivalent circuit parameters), unlike brute force optimization methods. The extracted ECPs can be fit to a linear temperature dependence:

$$ECP(V_g, V_{ds}, T) = ECP(V_g, V_{ds}, T_0) [1 + B(V_g, V_{ds})(T - T_0)]$$

Where $T_0 = 300K$ and B is the temperature coefficient for a given ECP, usually expressed in parts per thousand.

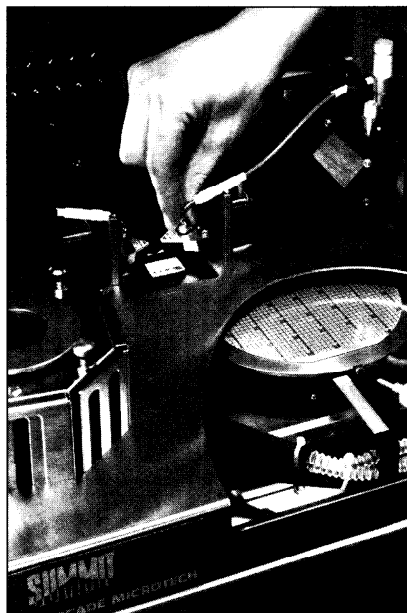


Figure 1. Cascade's MicroChamber found on both manual and semi-automatic probing systems.

Thermal Probing

Essential features of a thermal probing system include:

- Dry, frost-free probing environment with fast purge time.
- Dark, EMI-isolated enclosure that reduces measurement uncertainty.
- Fast, accurate, stable wafer heating and cooling.
- Limited electrical drift of calibration standards, probes, and cables over temperature.
- Compensation capability for wafer expansion (TCE).

Cascade Microtech's patented MicroChamber™ provides all of these features.

Calibrating and Measuring

Calibration stability and measurement accuracy over temperature are the most important, and yet the most often neglected, thermal probing issues. The initial calibration

stability of your system should be greater than -60 dB or 0.1%. You need to perform a new calibration whenever the stability reaches -40 dB or 1%.

These factors affect calibration stability:

- Instrument variations over time.
- Probe placement errors resulting from the wafer chucks thermal expansion.
- Changes in the calibration standards with temperature.
- Electrical drift, due to probe and cable temperature variations.

To ensure measurement integrity, check calibration stability frequently.

As the chuck changes temperature, it expands and contracts. The total chuck expansion (from -65° C to +200° C) is about mils. This affects probe overtravel. At each temperature, you need to adjust the overtravel of the probe tips. In addition, the wafer diameter changes with temperature, resulting in small spacing changes between devices. Cascade's Summit-series of semi-automatic thermal probe stations include control software that automatically compensates for these changes. This minimizes the impact on measurement accuracy.

Calibration Methods and Stability

You can use the LRM, LRRM, SOLT, and TRL calibration methods for over-temperature measurements. Although often ignored, the implementation of custom calibration software greatly affects calibration accuracy. For example, you must consider variations in the dielectric constant of the substrate material, via hole integrity, or changes in the load (match) standard with temperature. To avoid these difficult issues, use Cascade's

calibration software and ISS. LRM and LRRM are the preferred calibration techniques. The primary consideration with LRM or LRRM standards is the sensitivity of the 50-ohm load standard to temperature variations. The thermally isolated auxiliary stages on the Summit 10600-series probe station minimize the temperature variation of this load, by reducing the temperature excursions of the calibration elements. A main chuck temperature range of -65°C to $+200^{\circ}\text{C}$ corresponds to an auxiliary stage temperature range of about $+5^{\circ}\text{C}$ to $+65^{\circ}\text{C}$. This smaller temperature excursion reduces the total variation in the load resistance to about 0.7%. LRM standards fabricated on-wafer have greater variations, perhaps as large as 3%.

Changes in the probes and cables greatly impact calibration and measurement accuracy. With a $+200^{\circ}\text{C}$ chuck temperature, the associated coaxial connector temperature is about $+75^{\circ}\text{C}$. Since the probes directly contact the substrate, the coax connector and coax-to-coplanar transition experience significant thermal changes. Experiments show that these changes are large enough to require new calibrations at each temperature.

Figure 2 illustrates the changes observed in calibration stability for a room temperature calibration after the chuck changes to $+200^{\circ}\text{C}$. The

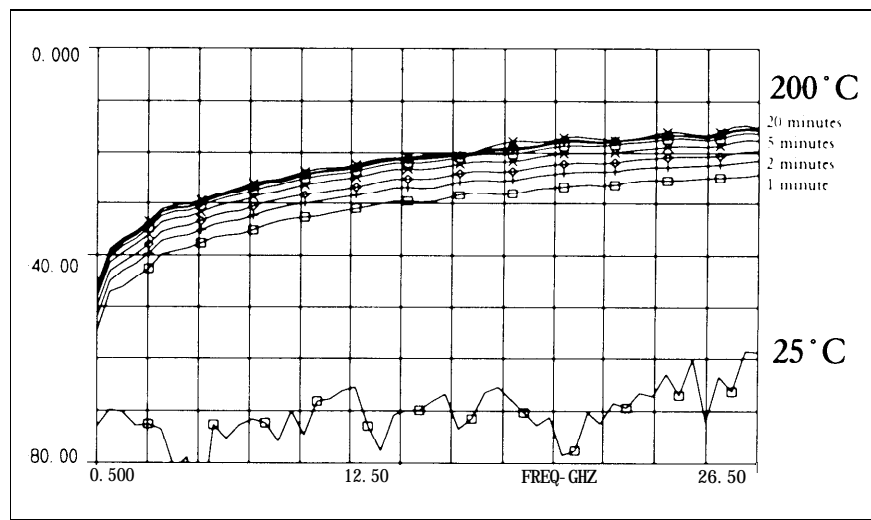


Figure 2. Calibration stability at 200°C for a 25°C calibration.

calibration stability is unacceptable. Note that the probe continues to change during the first 15 minutes. For optimal results, therefore, allow a 15-minute probe stabilization period at each temperature.

Measurement Issues

Along with probe temperature, there are measurement considerations. These include RF power levels, resistive loss in the bias lines, and device stability. At low temperatures, the device gain increases considerably. To ensure linear operation over the entire temperature range, adjust the RF power levels to the device.

Finally, you must consider device stability. Due to the

potentially high gain at low temperatures, some devices may oscillate. Take precautions to ensure stability.

General Extraction Results

Considerable activity is taking place in the area of temperature-dependent device modeling. Although most work focuses on GaAs MESFET technology, PHEMT and HBT modeling efforts continue to increase. Figure 3 shows typical ECP temperature coefficients for a $0.5 \times 200 \mu\text{m}$ MESFET device.

Summary

Points to remember are:

- Room temperature calibrations are not valid for over-temperature measurements.
- Stabilize probes and cables for at least 15 minutes before performing a calibration.
- Check calibration stability frequently.
- Implementation of custom calibration standards requires careful consideration.

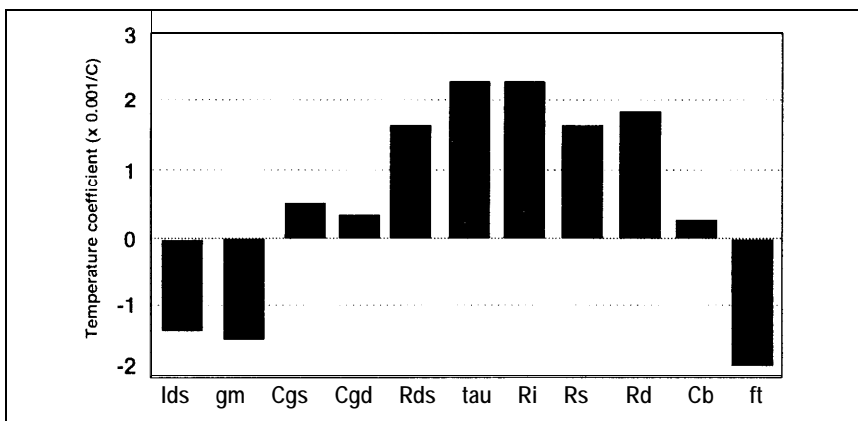


Figure 3. Temperature coefficients for $0.5 \times 150 \text{ mm}$ MESFET.



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