Reflectivity of Rough Copper Surfaces at Submillimeter Wavelengths

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Submillimeter radiation is interesting for numerous applications including concealed weapon detection, high resolution remote imaging, fusion plasma diagnosis, and chemical spectroscopy. Effective design of sources, detectors and system components for submillimeter wavelength radiation requires the ability to predict the amount of dissipation loss caused by conducting surfaces. However, the theoretical understanding of the conductivity of metals is incomplete beyond 100 gigahertz (GHz). Electromagnetic simulation tools, used in submillimeter device design, would be enhanced by improved models for metal conductivity as a function of frequency and surface characteristics. Confirming such a theory is difficult because experimental measurements in this regime are unavailable, unrepeated or even contradictory.

Surface roughness plays an important role in submillimeter-wave devices. Metal components produced by additive (electroplating, sputtering) or subtractive (etching, machining) processes will result in a rough surface interacting with the electromagnetic wave. The reflectivity of the surface will be affected significantly when the resulting roughness is comparable in size to the skin depth. Between 400 and 850 GHz the skin depth in copper varies from approximately 100 to 70 nm, respectively. Tsang, et al. (Tsang L., IEEE Trans. Adv. Packaging, **33,** 839–856, 2010) have developed a theory for predicting the reflection loss of a wave from a rough metal surface. They show that realistic, isotropic, rough surfaces are characterized by a spatial spectral density function that determines the surface reflectivity. This theory is more sophisticated than the commonly-used Hammerstad-Bekkadal formula (Hammerstad E. and Jensen O., Microwave symposium Digest, 1980 IEEE MTT-S International 407, 1980) which requires knowledge of just the average roughness and skin depth of a surface.

We will present measurements of the submillimeter-wave reflectivity of copper surfaces. The surfaces under test were fabricated with controlled roughness. The sizes of the roughness range from very smooth (~5 nm) up to tens of nanometers, similar to the skin depth. These measurements were performed using a unique high quality factor quasi-optical hemispherical resonator operating between 400 and 850 GHz. We will compare these measurements to the predictions of several theories, including the Sommerfeld theory of electronic conduction, the classical relaxation effect model of surface impedance, and the rough surface reflectivity theories of Hammerstad, et al. and Tsang, et al. In addition to the surface morphology, we have also measured the grain size and resistivity of these samples. Since the reflectivity is affected by both the microstructure and surface roughness, these measurements will allow us to isolate and accurately quantify the influence of both characteristics.