Materials for Wireless Communications

The current revolution in wireless communications would not have been possible without the discovery and development of oxide ceramics exhibiting the coincidence of high, temperature-independent permittivity with low dielectric loss. Advanced ceramics are primarily used as building blocks for filters and oscillators in components that are critical to the performance of the end application. One of the first ceramics widely used for cellular base stations was discovered, and its processing phase diagram determined, in a collaborative effort between Bell Labs and NBS in the early 1970's. Today, wireless technologies constitute one of the most important growth areas in the world electronics industry. Paramount in the cost-cutting and miniaturization process is the need for research that will facilitate the rational design of advanced materials to provide temperature stability, frequency, and size-reduction requirements for the next generation of devices for cellular, PCS, and many other niches of the wireless communications industry.

Technically important ceramic materials fall into two major dielectric categories; namely, bulk ceramics for base station resonators/filters, and those needed for low-power, miniaturized hand-held devices requiring thick and/or thin films in an integrated structure. Ceramics Division activities include research on both types of dielectric materials. The primary goal of the program is to determine methods that can be used to predict high-frequency dielectric behavior to enable rational design of next-generation ceramics.

Current research on ceramic materials for base station applications includes experimental determination of selected complex-oxide phase diagrams integrated with in-depth structural (X-rays, electrons, neutrons), crystal-chemical, spectroscopic, and dielectric property characterization. The objective of this multidisciplinary project is to determine the fundamental relationships between phase chemistry, crystal structure, and dielectric performance at wireless frequencies. This work is performed in collaboration with personnel in the Radio-Frequency Technology Divisions.

Another project uses first-principles (FP) methods to elucidate the roles of cation order-disorder and ferroelastic phenomena in determining the phase relations and physical properties of complex ceramic oxide systems. Typically, these materials exhibit exploitable ferroelectric, dielectric, or magnetic properties, and are widely used in technical applications such as transducers, multilayer capacitors, dielectric resonators, or dielectric filters. First- principles calculations are used to predict cation ordering phenomena, physical properties, and how they vary with chemical composition. Critical experiments are performed to test the predictions. An additional technical objective is to benchmark various FP techniques that are used to compute physical properties and the formation energies on which the calculations are based.

Microstructural modeling and experimental studies are also underway to determine the dimensional changes in low-temperature-cofired ceramics used for portable communication devices. Models developed in this study were identified by a large segment of industrial producers as being crucial toreducing the time for the design and production of components.

Related work in the Materials Reliability Division includes development of noncontact acoustic metrology to characterize wireless materials in both thin-film and bulk form. The mechanical properties of thin films are investigated using laser-ultrasonic methods to generate and detect surface acoustic waves. The elastic-property information obtained will result in improved predictive modeling of film performance. In another project, resonant-ultrasonic techniques are applied to new piezoelectric materials for SAW devices, used extensively as oscillators in hand-held devices. These measurements probe fundamental damping mechanisms that underlie intrinsic acoustic loss and hence affect device performance.

In the Polymers Division, the electromagnetic properties of polymer composite films are investigated for applications in wireless communications. These materials can be used to construct RLC cells and de-coupling power planes integrated within chip substrates and printed circuit sub-assemblies. Current technologies utilizing discrete components cannot provide adequate solutions at frequencies above 1 GHz that are critical for the high-speed electronics needed by wireless technologies. In partnership with the National Center for Manufacturing Science and industry, a collaborative research consortium was organized to address this inherent problem. NIST staff contribute materials science expertise, and specialized test vehicle designs and procedures for dielectric testing of high-k polymer composite films at microwave frequencies.

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