Center for Dielectric Studies (CDS)

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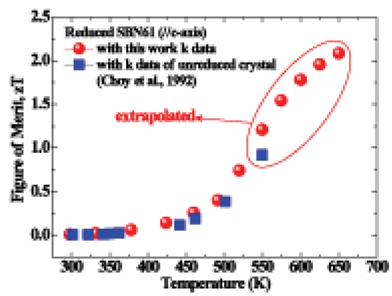
Thermoelectric Materials from Ferroelectrics

Thermoelectric materials are a very interesting concept that has the potential to harvest waste heat and convert it to electrical energy. This is particularly attractive for exhausts in automobiles. Based on analysis of the automotive area alone, which represents only one possible application of this research, automobiles lose up to 70% with heat loss. It is feasible, with state-of-the-art heat exchanges coupled with high ZT, thermoelectric generation could give up to 8 to 10% improvement in fuel consumption.

Thermoelectric materials require specific properties that are enhanced with electrical conduction and high Seebeck coefficients and low thermal conductivity. Ferroelectric materials have low thermal conductivity. Using heavy defect doping, CDS researchers have converted traditional materials from insulating to thermoelectrics in oxide materials, such as (Sr, Br)Nb2O6-d. Some of our members are following this new research area.

> **Economic Impact:** At this time, the thermoelectrics worldwide business is approximately $60 million. However, there are roadmaps in Europe, the US and Asia to use thermoelectric generators to aid car fuel efficiency between 2014 and 2026. If successful, this industry will expand to a $20 billion industry.



Very high n-type ZT behavior in the reduced single crystals of (Sr,Ba)Nb2O6-d. The thermal conductivities used in this are in excellent agreement with the reported data, higher temperatures. Data are taken through measured thermal power and extrapolated thermal conductivity measurements. ZT˜1 are clearly obtained in the c-direction of SBN.

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An Electrical Measuring Approach Towards High Reliability Electronics

Embedded electronics medical therapy requires the highest levels of reliability in electronic systems. The research on reliability at the CDS gives fundamental insights into the lifetime changes that occur in capacitor devices under use. The details of these mechanisms lie with complex interplay between the thermochemical and electrochemical processes that at the atomistic level limit long term stability. The techniques that the Center has developed, such as site-specific impedance spectroscopy and thermally stimulated depolarization current measurements, indicate the nature of processes and introduce methodologies that can quantify the defects that promote electrochemical processes in use.

Implantable cardiac defibrillator

Economic Impact: Reliability testing is a must in high-end electronics. Methods such as those being developed at CDS apply due diligence on all components in embedded electronic systems and protect manufacturers the customers in an essential industry that was about $10.7 billion worldwide in 2010. US companies, such as Boston Scientific, have adapted center based reliability methods to screen components that are inside the cardiac defibrillator. Through these techniques, suppliers and end-users such as Boston Scientific can assess opportunities for manufacturing that can provide the industry with the best performing capacitors.

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Increasing the Performance in Electrolytic Capacitors

To enhance capacitance and voltage performance in electrolytic Ta capacitors, companies such as Cabot Corporation, KEMET Electronics Corporation, and Greatbatch, Inc., are interested in the CDS studies on the fundamentals of anodization and the nature of the dielectric produced under different processing conditions. The point defect model has been extended to address the problems of Ta-anodization and provides unique insights into the relative roles of thermal and anodized dielectric. With these new models, it is believed that there are more methodologies at hand to extend the high capacitance from high surface area Ta powders. In addition, with higher voltage Ta electrolytics, understanding the details of the conduction mechanisms with trap densities and curvatures is helping our CDS companies design state-of-the-art capacitors for new application areas in power electronics.

Economic Impact: Electrolytic capacitors impact all of the electronic industry, ranging from computers, communications, power supplies, automobile, aerospace, medical, and military. The Ta-electrolytic market is approximately $4 billion.

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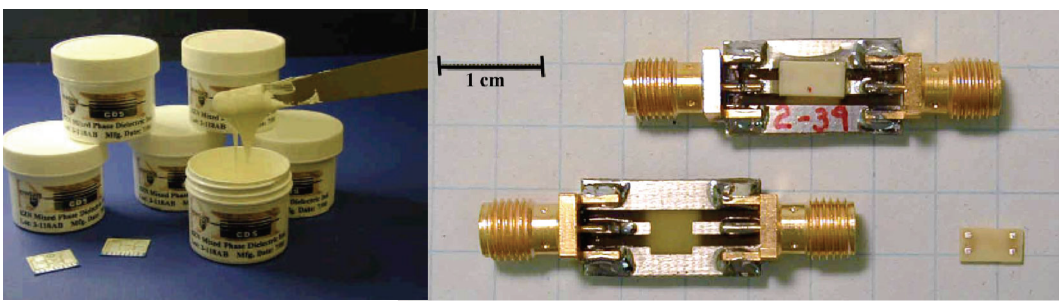
New Products and Process Improvements for Passive Electronic Components

Passive electronic components have not undergone the same miniaturization as have other semiconductor components. This creates important constraints in terms of space consumption on circuit boards. Efforts have been made to make these components smaller, less expensive and generally more compatible with consumer electronics. Research at the Center for Dielectric Studies (CDS) has helped researchers at AVX Corporation better understand the materials and processes used to make electronic components. AVX is a passive electronic component manufacturing company that makes capacitors, resistors, and inductors, parts that control flow of current in circuits. Specifically, this center's work has led to implementation of processes at AVX for preparation and heat treatment of capacitors, innovations that led to improvements in yield in product lines.

> **Economic Impact:** The world market for capacitor components is estimated to be $16 billion US dollars annually. Passive electronic components are constantly evolving to support system trends in functionality and miniaturization, such as in handheld electronics.



Thick film paste made from a new high permittivity, low loss dielectric for microwave passive component integration (left); Prototyped microwave filter components manufactured with a new high permittivity pyrochlore materials (right).

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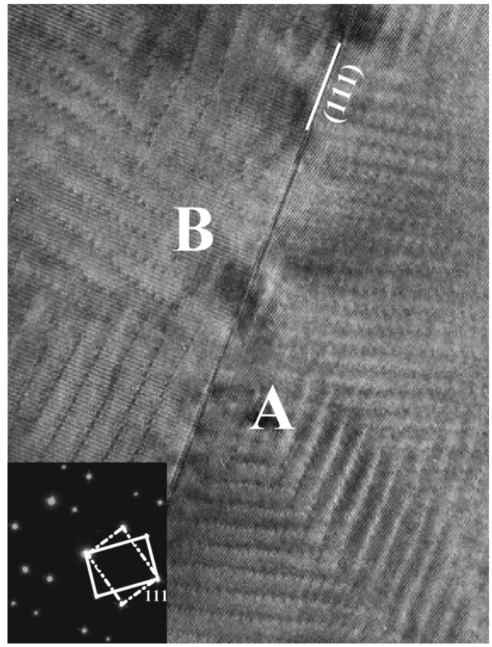
Understanding Dielectric Materials

Research at the Center for Dielectric Studies (CDS) has furthered understanding of dielectric materials, including the requirements for raw materials and the properties that result from various compounds and processing approaches. One such company is Ferro Corporation, one of the largest manufacturers of barium titanate in the world. The Center's research has shed new light on understanding the defect chemistry of barium titanate, a key ingredient of many of the dielectric powders. Related center research on mechanisms of failure in multilayer ceramic capacitors, particularly capacitors with Ni electrodes, helped to improve yields using state-of-the-art microscopy techniques as illustrated in the figure.



Local failure sites identified in a multilayer capacitive component. These regions are then removed by state-of-the-art techniques to analyze the underlying defect structures at the nanometer length scale.

Economic Impact: The world market for capacitor components is estimated to be $16 billion US dollars annually. Passive electronic components are constantly evolving to support system trends in functionality and miniaturization, such as in handheld electronics, reliability is a very import part of their value.

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