AD-A270 037

(2)

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
01 October 1992 through 30 September 1993

R&T Number: 4324893

Contract/Grant Title: N0001493/0110

Scientific Officer: Barsom

Principal Investigator: SUO

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a. Number of Papers Submitted to Referred Journal but not yet published: 3

b. Number of Papers Published in Referred Journals: (List Attached): 1

c. Number of Books or Chapters Submitted but not yet Published: 0

d. Number of Books or Chapters Published (List Attached): 0

e. Number of Printed Technical Reports & Non-Referred Papers (List Attached): 0

f. Number of Patents Filed: 0

g. Number of Patents Granted (List Attached): 0

h. Number of Invited Presentations at Workshops or Professional Society Meeting (List Attached): 1
Max-Planck-Institut, Stuttgart, Germany

i. Number of Presentations at Workshops or Professional Society Meetings (List Attached): 1
ASME Winter Annual Meeting 1992

j. Honors/Awards/Prizes for Contract/Grant Employees: (List Attached, may include Society Awards/Offices, Promotions, Faculty Awards/Offices, etc.) 1

National Science Foundation, Young Investigator Award, SUO

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k. Providing the following information will assist with statistical purposes.

PI/CO-PI:	TOTAL	1	Grad Students:**	TOTAL	1
	Female			Female	
	Minority*			Minority*	

Post Doc:**	TOTAL	1
	Female	
	Minority*	

1. Degrees Granted (List Attached): 0

* Underrepresented or minority groups include Blacks, Hispanics, and Native Americans.
Asians are not considered an underrepresented or minority group in science and engineering.

** Supported at least 25% this year on contract/grant.

Enclosure(1)

TECHNOLOGY TRANSFER

Technology transfer is an important measure of the relevance of scientific endeavors. ONR scientific officers need to be aware of any such transfer, and they will use it to the benefit of their programs. Please describe any recent (approximately last three years) direct or indirect interactions you had with Navy, other DoD, or industrial scientists and engineers; describe only those interactions that resulted in their use of methodology, data, software, or other developments produced or directly derived from your ONR grant/contract. Also describe similar technology transfer, if any, that resulted without any such interactions.

None

Enclosure (2)

LIST OF PUBLICATIONS/REPORTS/PATENTS/GRADUATES

1. Papers Published in Referred Journals:

   Z SUO · Models for breakdown-resistant dielectric and ferroelectric ceramics. J. Mech Phys. Solids. 41, 1155–1176, 1993

2. Books (and sections thereof) Published:

   None

3. Technical Report, Non-Refereed Papers:

   None

4. Presentations:

   ASME Annual Meeting 1992: breakdown-resistant dielectrics. presented by SUO

5. Patents Granted:

   None

6. Degrees Granted (name, date, degree):

   None

Enclosure (3)

LIST OF AWARDS/HONORS/PRIZES

Name of Person Receiving Award	Recipient's Institution	Name of Award	Sponsor of Award
SUO	UCSB	National Science Foundation Young Investigator	National Science Foundation

OTHER SPONSORED RESEARCH

(Include title, sponsors's name, dollar amount and start and end dates for the award)

Mechanism-Based Design for High-Temperature, High Performance Composites, DARPA (with A.G. Evans, F.A. Leckie and J.W. Hutchinson *et al.*, 5/92-4/1997) $15,634,279.

Mechanics of Diffusive Failure of Interconnects in Integrated Circuits, NSF (PI: Z. Suo, 8/1992-7/1995). $180,000

Some Basic Mechanics Problems in Electronic Materials, Young Investigator Award, NSF (PI: Z. Suo, 8/1992-7/1997). $125,000 (base).

An Investigation on Degradation Mechanisms for Ferroelectric Actuator Design, ONR (PI: Z. Suo, 11/1992-11/1995). $450,000.

Enclosure (5)

FUNDING BALANCE

Please indicate the remaining ONR grant/contract resources you have in your institution as of 30 SEP 93. This information is important to the Scientific Officer's planning process and to ONR tracking of expenditure rates.

$ 85,000

Enclosure (6)

DEGREDATION MECHANISMS OF FERROELECTRIC CERAMIC ACTUATORS

ONR CONTRACT N00014-93-1-0110

ONR Program Manager: R.S. Barsoum

PI: Z. Suo
Mechanical and Environmental Engineering Department

Progress Report
15 November 1992 — 30 September 1993

This report covers the work completed in the period from 15 November 1992 to 30 September 1993. Four papers on degredation of ferroelectric oxides have been completed. X. Gong (graduate student), C.S. Lynch (post-doc), and W. Yang (visiting scholar) are supported by the program. A new graduate student Roland Loge will join the team in January 1994.

a. Research Goals

Ferroelectric oxides deform appreciably under electric field. They are used now as large strain ceramic actuators where a moderate electric voltage can deliver an appreciable mechanical motion. The electrostrictive and piezoelectric strains are incompatible around inhomogeneities, such as electrode edge and inclusions. Cracking under electric loading has been identified in recent years. This program seeks to quantify various cracking mechanisms so that future actuator design will have a scientific basis.

b. Significant Results in the Past Year

The abstracts of the papers are listed below. Both experiments and theories are pursued in this program. Crack growth under cyclic polarization switching is studied experimentally using a lead lanthanum zirconate-titanate ceramic [2]. We find that the crack growth rate is sensitive to temperature, loading magnitude and frequency. Several mechanisms have been proposed to account for the cyclic crack growth. One such model has been analyzed in detail [4]. More detailed experiments on such cracks are in progress.

Thin film ferroelectric oxides have received much attention in recent years. Potential applications include micro-machines, sensors, and memory devices. It is believed that various strain relaxation mechanisms affect the properties of the thin films. In [2] we study domain patterns in an epitaxial ferroelastic and ferroelectric films. A condition for the film to remain a single domain is derived. The model is now being generalized to include inclined domains, and relaxation due to dislocations.

1. Z. Suo, "Models for breakdown-resistant dielectric and ferroelectric ceramics," *J. Mech. Phys. Solids*. **41**, 1155-1176, 1993.

Models for dielectric breakdown are proposed and analyzed, with emphasis on concepts leading to breakdown-resistant materials. The Griffith energy balance is extended to cracks under combined electrical and mechanical loading, and to conductive tubular channels. Breakdown strength for a perfect crystal is estimated by an analogue of the Frenkel model. In a crystal subjected to an electric field the equilibrium displacement of the electron clouds is described by a curve with periodicity of the lattice constant. A theory of breakdown-resistant laminates is proposed on the basis of charge relocation, facilitated by breakdown of the weak layers and the interfaces. A process by which a conducting path grows like a crack in ferroelectric ceramics is discussed, followed by an outline of fields around conducting cracks in piezoelectric ceramics.

2. W. Pompe, X. Gong, Z. Suo and J.S. Speck, Elastic energy release due to domain formation in the strained epitaxy of ferroelectric and ferroelastic films. *J. Appl. Phys.* In press.

Twin related domain formation is examined as a strain relaxation mechanics for a heteroepitaxial tetragonal film on a cubic substrate. Elastic relaxations are calculated for a single twin band in which the c-axis of the tetragonal domains is either related by a 90° rotation about an axis in the plane of the film or by a 90° rotation about the surface normal. In all cases, the strain energy change is evaluated for both the film and the substrate. A domain pattern map is developed that predicts single domain and multiple domain fields depending on the relative misfit strains and domain wall energy. The concept in which the c-axis is rotated 90° about an axis in the plane of the film, the critical thickness depends only on the relative coherency strain between the substrate and film and the ratio of the domain wall energy to the stored elastic energy. For the case of a pattern consisting of energetically equivalent domains with the c-axis in plane, the equilibrium distance of multiple domains is derived. For such multiple domains, a minimum wall separation distance exists which depends nonlinearly on the film thickness.

3. Lynch, C.S., Chen, L., Yang, W., Suo, Z., and McMeeking, R.M. (1993) Crack growth in ferroelectric ceramics driven by cyclic polarization switching. To appear in *Proceedings of Adaptive Structures and Material Systems Symposium*, Ed. G. Carman and E. Garcia.

Ferroelectric ceramics are susceptible to stable crack growth under cyclic electric field of high magnitude. The stresses originate from mismatch strains induced by the electric field around inhomogeneities, such as processing flaws, terminated electrodes and the cracks themselves. The phenomenon is studied using a lead lanthanum zirconate-titanate ceramic. A flaw is indented on the surface of a ceramic sample. Subject to a cyclic electric field of magnitude exceeding the coercive field, cracks emanate form the flaw, in the direction perpendicular to the voltage drop. Tests relevant to the phenomenon are also performed. Polarization and strain as functions of applied electric field are measured at various temperatures and applied stresses. Discharge is demonstrated through an air gap between two ceramic plates subjected to a voltage drop. Models are presented that explain the cyclic nature of the crack growth.

4. W. Yang and Z. Suo, Cracking in ceramic actuators caused by electrostriction. Submitted to *J. Mech. Phys. Solids* August 31, 1993.

Many perovskite-type ceramics deform appreciably under electric fields. They make good actuators which deliver motions upon receiving electrical signals. High electric fields are usually applied to induce large strains. Cracking has been observed in the actuators under electrical loading. In this theoretical study, the phenomenon is examined on the basis of electrostriction and fracture mechanics. Attention is focused on a crack emanating from an internal electrode or a conducting damage path. At the edge of the conducting path, the electric field is intense and nonuniform, inducing incompatible electrostrictive strains. Consequently, a stress field is set up in the ceramic, localized around the edge of the conducting path. The condition for the stress to extend a crack is estimated by two models. It is found that, under a given electric field, cracking is suppressed in an actuator if each ceramic layer is sufficiently thin.

c. **Plans for Next Year's Research**

1. To substantiate the work described in paper 3, we will carry out more detailed measurement of crack growth rate, and the effects of external variables such as field magnitude, frequency, and temperature.

2. Extend the model of domain patterns in ferroelectric thin films to include 45° domain bands, which is believed to be prevalent in such systems.

3. Complete a finite element code for analyzing electrostrictive stresses around defects. The initial version of the code will include the complete non-linear but non-hysteretic electrostrictive constitutive laws.

4. We will carry out a set of exploratory experiments on conducting cracks using liquid electrolyte to mimic charged species in the environment. A special fixture has been designed and tried with good results.