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The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Michael Stroscio
UU	UU	UU	UU		19b. TELEPHONE NUMBER 312-413-2283

RPPR Final Report
as of 25-May-2018

Agency Code:

Proposal Number: 71161ELII **Agreement Number: W911NF-17-1-0334**
INVESTIGATOR(S):

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DUNS Number: 098987217 EIN: 376000511
Report Date: 30-Jun-2018 Date Received: 17-May-2018
Final Report for Period Beginning 01-Jul-2017 and Ending 31-Mar-2018
Title: Nanomechanical Systems with Normalized and Coupled Acoustic and Electromagnetic Modes in Piezoelectric Structures
Begin Performance Period: 01-Jul-2017 **End Performance Period:** 31-Mar-2018
Report Term: 0-Other
Submitted By: Michael Stroscio Email: stroscio@uic.edu
Phone: (312) 413-2283
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 0 **STEM Participants:** 3

Major Goals: This research deals with the quantization of the acoustic modes in nanomechanical systems with coupled acoustic and electromagnetic modes in piezoelectric structures. Specifically, the well-known Bleustein-Gulyaev (BG) modes in the theory of surface acoustic wave devices, are second quantized so that the relationship between the
acoustic modes and the electromagnetic modes can be examined in the limit where the acoustic mode is a single acoustic phonon. By considering a theory where the quantized acoustic phonons are explicitly related to the electromagnetic modes, this treatment allows a description of nanomechanical systems where acoustic and electromagnetic modes can be described in the nanoscale limit. This effort will examine quantitatively the electromagnetic-acoustic interaction caused by the piezoelectricity in the limit where the classical acoustic waves must be described in terms of phonons.

Accomplishments: This work demonstrated the quantization of the acoustic modes in nanomechanical systems with coupled acoustic and electromagnetic modes in piezoelectric structures. Specifically, the well-known Bleustein-Gulyaev (BG) modes in the theory of surface acoustic wave devices, were second quantized so that the relationship between the acoustic modes and the electromagnetic modes can be examined in the limit where the acoustic mode is a single acoustic phonon.

Training Opportunities: Three graduate students were support under this grant. In addition the PI was supported

Results Dissemination: Two refereed journal papers were published during this 9-month effort.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Two refereed journal articles were published during this 9-month grant.

PARTICIPANTS:

Participant Type: PD/PI
Participant: Michael Anthony Stroscio
Person Months Worked: 1.00 **Funding Support:**

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Debopam Datta
Person Months Worked: 3.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Ahmed Mohamad
Person Months Worked: 3.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Shreya Ghosh
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

ARTICLES:

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
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Publication Identifier Type: DOI Publication Identifier: http://dx.doi.org/10.1016/j.ssc.2017.09.009
Volume: 267 Issue: First Page #: 42
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Publication Location: New York
Article Title: Quantization of acoustic-phonon modes in Siedel-White type waveguide nanostructures
Authors: D. Datta, A. Darbandi, S. Ghosh, M.A. Stroscio, M. Dutta
Keywords: Semiconductor, Siedel-White type nanoscale waveguide, Acoustic-phonon Mode Quantization, Akheiser dissipation, Landau-Rumer dissipation
Abstract: Acoustic phonon modes in a rectangular nanoscale waveguide deposited on a substrate (Siedel-White type waveguide) are analyzed analytically in terms of the elastic continuum model and the modes are quantized under the dimensional confinement assumption. The rectangular isotropic overlay structure is assumed to be deposited on a substrate with larger area compared to the overlay, and perfectly rigid. The displacement field inside the rectangular overlay structure is described for structures with nanometer dimensions. The frequency dependence of the modes has been studied along with the modal profiles for different overlay dimensions. The phonon occupation number has been evaluated for a range of dimensions and temperatures and the frequencyquality factor (f.Q) product has been theoretically discussed and evaluated using the parameters for silicon.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Solid State Communications
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1016/j.ssc.2018.04.005
Volume: 277 Issue: First Page #: 1
Date Submitted: Date Published: 4/7/18 5:00AM
Publication Location: New York
Article Title: Nanomechanical systems with normalized and coupled acoustic and electromagnetic modes in piezoelectric structures
Authors: Ahmed Mohamed, Shreya Ghosh, Marcos Araque, Debopam Datta, Mojgan Mazouchi, Vaidehi Rane, M
Keywords: Bleustein-Gulyaev (BG),. Acoustic and electromagnetic modes, Piezoelectric structures, Quantization
Abstract: This paper deals with the quantization of the acoustic modes in nanomechanical systems with coupled acoustic and electromagnetic modes in piezoelectric structures. Specifically, the well-known Bleustein-Gulyaev (BG) modes in the theory of surface acoustic wave devices, are second quantized so that the relationship between the acoustic modes and the electromagnetic modes can be examined in the limit where the acoustic mode is a single acoustic phonon. By considering a theory where the quantized acoustic phonons are explicitly related to the electromagnetic modes, this treatment allows a description of nanomechanical systems where acoustic and electromagnetic modes can be described in the nanoscale limit. This effort will examine quantitatively the electromagnetic-acoustic interaction caused by the piezoelectricity in the limit where the classical acoustic waves must be described in terms of phonons.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

CONFERENCE PAPERS:

RPPR Final Report
as of 25-May-2018

Publication Type: Conference Paper or Presentation **Publication Status:** 0-Other
Conference Name: TANMS Annual Research Strategy Workshop
Date Received: Conference Date: 30-Jan-2018 Date Published: 30-Jan-2018
Conference Location: Los Angeles
Paper Title: Quantization of Phonon Modes in Nanoscale Waveguides and Resonators and Vibrational Modes in Biological Systems Michael A. Stroscio, Mitra Dutta, Debopam Datta, Mojgan Mazouchi, Shreya Ghosh, Marcos Araque, Ahmed Mohamed, Weidong Zhang, Elliott R. Brown, and Vaidehi Rane, Quantization of Phonon Modes in Nanoscale Waveguides and Resonators and Vibrational Modes in Biological Systems TANMS Annual Research Strategy Workshop, 30-31 January 2018 UCLA (lead talk in opening session) , 30-31 January 2018 UCLA (lead talk in opening session)
Authors: Michael A. Stroscio, Mitra Dutta, Debopam Datta, Mojgan Mazouchi, Shreya Ghosh, Marcos Araque, Ah
Acknowledged Federal Support: **Y**

Accomplishments and Progress

This paper deals with the quantization of the acoustic modes in nanomechanical systems with coupled acoustic and electromagnetic modes in piezoelectric structures. Specifically, the well-known Bleustein-Gulyaev (BG) modes in the theory of surface acoustic wave devices, are second quantized so that the relationship between the acoustic modes and the electromagnetic modes can be examined in the limit where the acoustic mode is a single acoustic phonon. By considering a theory where the quantized acoustic phonons are explicitly related to the electromagnetic modes, this treatment allows a description of nanomechanical systems where acoustic and electromagnetic modes can be described in the nanoscale limit. This effort will examine quantitatively the electromagnetic-acoustic interaction caused by the piezoelectricity in the limit where the classical acoustic waves must be described in terms of phonons. Emphasis was given to formulating a quantized treatment of BG modes that is amenable to the study of phonon engineering of the BG modes on the nanoscale. In particular, the elastic continuum model, was used to quantize the phonon amplitude analytically based on the analytical solutions for the BG modes. The analytical solutions of the BG modes provided a convenient starting point for the second-quantization of the acoustic modes which are required to model phonon effects properly in broad classes of nanostructures. This research The elastic continuum and dielectric continuum models are known to be accurate to the nanoscale regime; in particular, these models give an accurate representation of the normalized mode envelopes for structures even down to the scale on a couple of monolayers and for ensembles of as few as 60 atoms.

Under this grant, we analytically analyze the acoustic phonon mode properties in an isotropic overlay structure deposited on perfectly rigid substrate. As the substrate is assumed to be perfectly rigid, the acoustic energy will be completely bound within the overlay region. This kind of Siedel-White type waveguide structure is analyzed and quantized in terms of well-known analytical Siedel-White solutions. In addition, the phase characteristics of the waveguide structure were considered along with applicability in single mode operation. Moreover, we second quantized of classical acoustic modes within the overlay structure is performed and discussed. Finally, we computed the frequency-quality factor product (f. Q) for this typical structure.

In this work we have quantized the classical acousto-electromagnetic BG surface acoustic waves for the case of a grounded thin conducting film on a 6mm piezoelectric half space. This description facilitates the description of the BG modes in nanoscale surface acoustic wave devices in terms of phonons instead of classical acoustic waves and it describes the coupling between the acoustic waves (phonons) and the quanta of the EM field.