

Triboelectric Nanogenerators

Preface

Abstracts

List of Contents

Chapter 1: Triboelectrification

- 1.1 Nano energy and mega energy
- 1.2 Triboelectric effect
- 1.3 Quantification of triboelectrification
- 1.4 Materials for triboelectrification
- 1.5 The Van de Graaff generator
- 1.6 Triboelectric nanogenerators
 - 1.6.1 Vertical contact-separation mode
 - 1.6.2 Lateral sliding mode
 - 1.6.3 Single-electrode mode
 - 1.6.4 Freestanding triboelectric-layer mode
- 1.7 Perspectives
- References

Part A: Fundamental operation modes

Chapter 2: Triboelectric nanogenerator: vertical contact-separation mode

- 2.1 Basic principle
- 2.2 Fundamental theory
- 2.3 Basic device structures
 - 2.3.1 Spacer structure
 - 2.3.2 Arch-shaped structure
 - 2.3.3 Spring-assisted separation structure
 - 2.3.4 Multiple layer integration
 - 2.3.5 Microcavity-nanoparticle assembled structure
- 2.4 Summary
- References

Chapter 3: Triboelectric nanogenerator: lateral sliding mode

- 3.1 Basic principle

- 3.2 Fundamental theory
 - 3.2.1 Single-mode TENG with only one unit
 - 3.2.2 Grating TENGs
 - 3.2.2.1 Grating structure with equal-length plates
 - 3.2.2.1.1 Influence of electrode structure
 - 3.2.2.1.2 Influence of number of grating units
 - 3.2.2.2 Grating structure with unequal-length plates
 - 3.2.2.2.1 Influence of dielectric thickness
 - 3.2.2.2.2 Influence of number of grating units
- 3.3 Basic device structures
 - 3.3.1 Plain-sliding structure
 - 3.3.2 Linear-grating structure
 - 3.3.3 Rotation-disk structure
 - 3.3.4 Rotation-cylinder structure
 - 3.3.5 Case-encapsulated structure
 - 3.3.6 Liquid-metal structure
- 3.3 Energy conversion efficiency
 - 3.3.1 Solid-solid
 - 3.3.2 Solid-liquid
- 3.4 Summary
- References

Chapter 4: Triboelectric nanogenerator: single-electrode mode

- 4.1 Basic principle
- 4.2 Fundamental theory
 - 4.2.1 Basic working principle and electrostatic shield effect
 - 4.2.2 Effect of electrode gap distance
 - 4.2.3 Effect of area size (length)
 - 4.2.4 Effect of spacing between units for scale up
- 4.3 Basic device structures
 - 4.3.1 Contact-separation structure
 - 4.3.2 Lateral-sliding structure
- 4.4 Summary
- References

Chapter 5: Triboelectric nanogenerator: freestanding triboelectric-layer mode

- 5.1 Sliding freestanding triboelectric-layer TENG
 - 5.1.1 Basic principle
 - 5.1.2 Fundamental theory

- 5.2 Contact freestanding triboelectric-layer TENG
 - 5.2.1 Basic principle
 - 5.2.2 Fundamental theory
- 5.3 Advanced device structures
 - 5.3.1 Linear-grating structure
 - 5.3.2 Rotation-disk structure I
 - 5.3.2 Rotation-disk structure II
- 5.4 Rolling friction operation mode
- 5.5 Energy conversion efficiency
- 5.6 Summary
- References

Chapter 6: Theoretical modeling of triboelectric nanogenerators

- 6.1 Inherent capacitive behavior and governing equation V - Q - x relationship
- 6.2 First-order lumped-parameter equivalent circuit model
- 6.3 Charge reference state
 - 6.3.1 Influence of charge reference state on the intrinsic characteristics of TENGs
 - 6.3.2 Influence of charge reference state on the output characteristics of TENGs
 - 6.3.3 Typical charge reference states
- 6.4 Resistive load characteristics
 - 6.4.1 Resistive load characteristics and “three-working-region” behavior
 - 6.4.2 Optimum resistance
- 6.5 Capacitive load and charging characteristics
 - 6.5.1 TENG charging characteristics under unidirectional mechanical motion
 - 6.5.2 TENG charging performance under periodic mechanical motion
- 6.6 Summary
- References

Chapter 7: Figure of merits for quantifying triboelectric nanogenerators

- 7.1 Operation cycles of triboelectric nanogenerators
 - 7.1.1 V - Q plot and its characteristics
 - 7.1.2 Cycle of energy output
 - 7.1.3 Cycle of maximized energy output
 - 7.1.4 Experimental realization of the operation cycles
- 7.2 Figure-of-merits of triboelectric nanogenerators
- 7.3 Structural figure-of-merit: calculation and simulation
- 7.4 Measurement of material figure-of-merit
 - 7.4.1 Measurement of triboelectric surface charge density

7.4.2 Quantified triboelectric series based on normalized charge density and dimensionless surface charge density

7.5 Summary

References

Part B: Applications as a sustainable power source

Chapter 8: Harvesting body motion energy

8.1 Integrated structure of triboelectric nanogenerators

8.2 Fabric based triboelectric nanogenerators

8.2.1 Fiber based triboelectric nanogenerators

8.2.2 Textile based triboelectric nanogenerators

8.2.3 Fiber based hybrid nanogenerators

8.3 Paper based triboelectric nanogenerators

8.3.1 A single paper based triboelectric nanogenerators

8.3.2 A paper origami based triboelectric nanogenerators

8.4 Human skin based single-electrode mode triboelectric nanogenerators

8.5 Sliding freestanding-triboelectric-layer mode triboelectric nanogenerators

8.6 Summary

References

Chapter 9: Harvesting vibration energy

9.1 Vibration energy harvesting with basic operation modes

9.1.1 Vertical contact-separation mode

9.1.2 Contact single-electrode mode

9.1.3 Contact freestanding-triboelectric-layer mode

9.2 Vibration energy harvesting with advanced structural designs

9.2.1 Multi-directional vibration energy harvesting

9.2.2 Multi-layer structural design

9.2.3 Liquid-metal based structural design

9.3 Sound wave energy harvesting

9.3.1 Organic film based TENG

9.3.2 Rollable paper based TENG

9.4 Summary

References

Chapter 10: Harvesting wind energy

10.1 Wind energy harvesting based on rotational structure

- 10.1.1 Rotational sliding freestanding-triboelectric-layer mode wind-driven triboelectric nanogenerators
- 10.1.2 Other rotational structures for wind energy harvesting
- 10.2 Wind energy harvesting based on flutter-driven triboelectrification
 - 10.2.1 The first flutter-driven TENG for wind energy harvesting
 - 10.2.2 Elasto-aerodynamics-driven triboelectric nanogenerator
- 10.3 Summary
- References

Chapter 11: Harvesting large-scale blue energy

- 11.1 TENG for water wave energy harvesting
 - 11.1.1 Liquid-solid electrification-enabled TENG
 - 11.1.2 TENG based hydrokinetics energy harvesting
 - 11.1.3 Dual mode TENG for electrostatic and mechanic energies harvesting
 - 11.1.4 Fully enclosed TENG for water wave energy harvesting
- 11.2 Network of TENGs for blue energy harvesting
- 11.3 Summary
- References

Chapter 12: Hybrid cell composed of triboelectric nanogenerator

- 12.1 AC-AC hybrid cell
 - 12.1.1 Hybrid electromagnetic and triboelectric nanogenerator
 - 12.1.1.1 Theoretical comparison and conjunction operations of electromagnetic generator and triboelectric nanogenerator
 - 12.1.1.2 Rotating-disk-based hybridized electromagnetic-triboelectric nanogenerator
 - 12.1.2 Hybrid triboelectric-piezoelectric/pyroelectric nanogenerator
 - 12.1.2.1 R-shaped hybrid triboelectric-piezoelectric nanogenerator
 - 12.1.2.2 Hybrid triboelectric-pyroelectric energy cell
 - 12.1.2.3 Triboelectric-pyroelectric-piezoelectric hybrid cell for high-efficiency energy harvesting
- 12.2 AC-DC hybrid cell
 - 12.2.1 Hybrid solar cell and triboelectric nanogenerator
 - 12.2.1.1 Hybrid solar cell and triboelectric nanogenerator to harvest solar and mechanical energies
 - 12.2.1.2 Hybridized power panel to simultaneously generate electricity from sunlight, rain drops and wind around the clock
 - 12.2.2 Hybrid thermoelectric cell and triboelectric nanogenerator
 - 12.2.3 Hybrid electrochemical cell and triboelectric nanogenerator
- 12.3 Summary

References

Chapter 13: Applications in self-powered systems and processes

- 13.1 Integration of TENG with energy storage units for sustainably driving portable electronics
 - 13.1.1 Direct integration and transformer integration
 - 13.1.2 Through power management circuit board
- 13.2 TENG for self-powered electrochemical applications
 - 13.2.1 Self-powered electrochemical degradation
 - 13.2.2 Self-powered water splitting
 - 13.2.3 Self-powered anticorrosion
 - 13.2.4 Self-powered air filtering
 - 13.2.5 Self-powered electrochemical recovery
 - 13.2.6 Self-powered electrochromic device for smart window system
- 13.3 TENG for self-powered biomedical stimulation
 - 13.3.1 In-vivo implanted TENG for self-powered pacemaker
 - 13.3.2 Implantable self-powered laser cure system for proliferation and differentiation of cells
- 13.4 Summary
 - References

Part C: Applications as self-powered active sensors

Chapter 14: Self-powered sensing for human-machine interface

- 14.1 Self-powered pressure/touch sensor
 - 14.1.1 Contact-separation mode self-powered pressure sensor
 - 14.1.2 Single-electrode mode self-powered pressure sensor
 - 14.1.3 Dual-mode ultrasensitive self-powered pressure sensor
- 14.2 Self-powered tactile imaging
- 14.3 Self-powered smart keyboard
- 14.4 Summary
 - References

Chapter 15: Self-powered sensing for vibration and biomedical monitoring

- 15.1 Self-powered vibration sensor
 - 15.1.1 Position tracking of the vibration source
 - 15.1.2 Vibration amplitude measurement
- 15.2 Self-powered acoustic sensor for voice recording
 - 15.2.1 Helmholtz-cavity-based acoustic sensor
 - 15.2.2 Ultrathin paper-based acoustic sensor
- 15.3 Self-powered biomedical monitoring

- 15.3.1 Eardrum inspired bionic membrane sensor
 - 15.3.1.1 Self-powered arterial pulse wave measurement
 - 15.3.1.2 Self-powered throat-attached microphone
 - 15.3.1.3 Arterial pulse as a biometric recognition
 - 15.3.1.4 Multi-modal biometric authentication
- 15.3.2 Membrane-based triboelectric sensor
- 15.4 Summary
- References

Chapter 16: Self-powered sensing for tracking moving objects

- 16.1 TENGs as self-powered linear displacement sensors
- 16.2 TENGs as self-powered active rotation sensors
- 16.3 TENGs for self-powered tracking of a moving object
- 16.4 TENG as self-powered acceleration sensors
- 16.5 Summary
- References

Chapter 17: Self-powered sensing for chemical and environmental detection

- 17.1 Self-powered chemical sensors
- 17.2 Self-powered UV sensors
- 17.3 Self-powered environmental monitoring
- 17.4 Summary
- References

Appendix:

Appendix A: List of symbols for each chapters

Appendix B: List of abbreviations for each chapters

Appendix C: Journal articles by Wang's group on Triboelectric Nanogenerators (2012-2016)