

Flexible, Printed and Thin Film Batteries 2019-2029

By IDTechEx research - Dr Xiaoxi He

Flexible, Thin, Stretchable, Rollable, Bendable, Foldable, Micro- and Large-Area Batteries for Applications in Wearable Devices, Skin Patches, Healthcare and Cosmetics, Internet of Things and People, Portable Electronics, RFID, Smart Packaging and more

The battery market has suddenly become alive again in recent years. On one hand, batteries are moving to new form factors, becoming ultra-thin, flexible, rollable, stretchable, etc. On the other hand, manufacturers are scrambling to offer large batteries aimed at addressing the large-sized electric vehicle, residential and grid applications. This market study is focused on the former. IDTechEx has been tracking the technology development, market progress and player activities of global flexible, thin-film, printed batteries (or batteries with novel form factors) since 2014.

Table of Content

1. EXECUTIVE SUMMARY AND CONCLUSIONS
 - 1.1. Overview
 - 1.2. Thin-film, flexible, printed batteries, and beyond
 - 1.3. Structure of the report
 - 1.4. Who should read this report
 - 1.5. Research methodology
 - 1.6. Future Direction of Battery Development
 - 1.7. Status of battery markets
 - 1.8. Thin, flexible and printed batteries are describing different aspects of battery features
 - 1.9. Major drivers for the development of new-form-and-structural-factor batteries
 - 1.10. Status of flexible batteries
 - 1.11. Value proposition
 - 1.12. Challenges and difficulties
 - 1.13. Battery safety
 - 1.14. Samsung's firegate
 - 1.15. Development roadmap of batteries
 - 1.16. Application market roadmap
 - 1.17. Consumer electronics giants are moving into flexible batteries
 - 1.18. LG Chem's offerings
 - 1.19. Apple's contributions
 - 1.20. Samsung — never falling behind
 - 1.21. Nokia's approach
 - 1.22. Threats from other power sources
 - 1.23. Typical specifications for a CR2032 lithium coin battery
 - 1.24. Coin cell or thin battery, that is the question
 - 1.25. Advantages and limitations of supercapacitors
 - 1.26. Are supercapacitors threats to batteries?
 - 1.27. Trends towards multiple energy harvesting
 - 1.28. Comparison of different power options

- 1.29. Technologies included in the report
- 1.30. Technology benchmarking
- 1.31. Business model
- 1.32. A practical battery is a combination of many considerations
- 1.33. Strategies for battery providers focusing on new form and structural factors
- 1.34. Market by territory
- 1.35. Price perspectives
- 1.36. Addressable market
- 1.37. Market forecast assumptions
- 1.38. Market forecast 2019-2029 by application (number of units)
- 1.39. Market value forecast 2019-2029 by application
- 1.40. Market by application in 2019 and 2029
- 1.41. Market value forecast 2019-2029 by technology
- 1.42. Conclusions
2. BACKGROUND OF BATTERY KNOWLEDGE
- 2.1. What is a battery?
- 2.2. Glossary of terms - specifications
- 2.3. Useful charts for performance comparison
- 2.4. Battery categories
- 2.5. Commercial battery packaging technologies
- 2.6. Comparison of commercial battery packaging technologies
- 2.7. Electrode design & architecture: important for different applications
- 2.8. Electrochemical inactive components in the battery
- 2.9. Primary vs secondary batteries
- 2.10. Popular battery chemistries
- 2.11. Primary battery chemistries and common applications
- 2.12. Numerical specifications of popular rechargeable battery chemistries
- 2.13. Battery technology benchmark
- 2.14. Nomenclature for lithium-based rechargeable batteries
- 2.15. Lithium-ion & lithium metal batteries
- 2.16. Lithium-ion batteries
3. WHY IS BATTERY DEVELOPMENT SO SLOW?
- 3.1. Overview
- 3.2. A big obstacle — energy density
- 3.3. Battery technology is based on redox reactions
- 3.4. Electrochemical reaction is essentially based on electron transfer
- 3.5. Electrochemical inactive components reduce energy density
- 3.6. The importance of an electrolyte in a battery
- 3.7. Cathode & anode need to have structural order
- 3.8. Failure story about metallic lithium anode
- 3.9. Conclusion
4. THIN FILM BATTERIES
- 4.1. A thin battery is usually flexible to some extent
- 4.2. Typical thicknesses of the traditional battery components
- 4.3. Design differences between thin-film batteries and bulk-size batteries
- 4.4. Areal energy density vs. cell thickness
- 4.5. Shortcomings of thin-film batteries
- 4.6. Units used to characterize thin-film batteries
- 4.7. Comparison of various solid-state lithium-based batteries
- 4.8. Solid-State Thin-Film Lithium Battery
- 4.9. Most successful commercial thin-film battery
- 4.10. Players worked and working on thin-film lithium batteries

- 4.11. Construction of an ultra-thin lithium battery
- 4.12. Cathode material options for thin-film batteries
- 4.13. Cathode of thin film lithium battery
- 4.14. Anode of thin film lithium battery
- 4.15. Substrate options
- 4.16. Advantages and disadvantages of selected materials
- 4.17. Trend of materials and processes of thin-film battery in different companies
- 4.18. Ultra-thin micro-battery—NanoEnergy®
- 4.19. Micro-Batteries suitable for integration
- 4.20. From limited to mass production—STMicroelectronics
- 4.21. Summary of the EnFilm™ rechargeable thin-film battery
- 4.22. NGK
- 4.23. NGK's EnerCerachip
- 4.24. Thin-film solid-state batteries made by Excellatron
- 4.25. Johnson Battery Technologies
- 4.26. JBT's advanced technology performance
- 4.27. Capacity increase
- 4.28. Technology of Infinite Power Solutions
- 4.29. Cost comparison between a standard prismatic battery and IPS' battery
- 4.30. Manufacturing Approaches of Solid-State Thin-Film Lithium Batteries
- 4.31. Summary of main fabrication technique for thin film batteries
- 4.32. PVD processes for thin-film batteries
- 4.33. Thin-film battery potentials
- 5. BATTERY SIZE REDUCTION: MICRO-BATTERIES
- 5.1. Architectures of micro-batteries
- 5.2. Introduction to micro-batteries
- 5.3. 3D printed lithium-ion micro-batteries
- 5.4. Primary Li/CFx micro-battery
- 6. BATTERIES WITH SPECIAL MECHANICAL PROPERTIES: FLEXIBLE, STRETCHABLE, ROLLABLE, BENDABLE AND FOLDABLE BATTERIES
- 6.1. Flexible electronics
- 6.2. Realization of batteries' mechanical properties
- 6.3. Thickness-Derived Flexibility
- 6.4. Stresses generated in a the battery during flexing
- 6.5. Material-Derived Flexibility
- 6.6. Comparison of a flexible LIB with a traditional one
- 6.7. Introduction
- 6.8. Efforts on the electrolyte/ separator
- 6.9. Solid-state electrolyte
- 6.10. Safety of solid-state batteries
- 6.11. Improvement of solid-state battery
- 6.12. Comparison of organic and inorganic solid-state electrolyte
- 6.13. Polymer-based electrolytes
- 6.14. Bendable lithium-based battery
- 6.15. Lionrock Batteries
- 6.16. Highly conductive polymer gel electrolyte and lamination processes for roll-to-roll li-ion cell production
- 6.17. BrightVolt batteries
- 6.18. BrightVolt product matrix
- 6.19. Electrolyte
- 6.20. Toes Opto-Mechatronics
- 6.21. Hitachi Zosen's solid-state electrolyte
- 6.22. Hitachi Zosen's batteries

- 6.23. Hitachi Maxell
- 6.24. Ohara / PolyPlus
- 6.25. Planar Energy
- 6.26. ProLogium: Solid-state lithium ceramic battery
- 6.27. LiPON-based solid-state batteries
- 6.28. Ilika's stacked solid-state micro-battery
- 6.29. Thin film vs. bulk solid-state batteries
- 6.30. Efforts on the electrodes
- 6.31. Innovative electrode
- 6.32. From electrode innovation to flexible batteries
- 6.33. Efforts on the current collectors
- 6.34. Carbon materials for current collectors
- 6.35. Thin and flexible alkaline battery developed by New Jersey Institute of Technology
- 6.36. Flexible battery achieved by anode materials
- 6.37. Efforts on the packaging
- 6.38. Lithium-polymer pouch cells
- 6.39. Techniques to fabricate aluminium laminated sheets
- 6.40. Packaging procedures for pouch cells
- 6.41. IGMBPOW
- 6.42. Showa Denko Packaging
- 6.43. Flexible lithium-ion battery from QinetiQ
- 6.44. Semiconductor Energy Laboratory
- 6.45. Flexible and foldable batteries: still working after being washed by the washing machine
- 6.46. Flexible pouch cells
- 6.47. LIBEST's flexible battery
- 6.48. Panasonic's flexible batteries
- 6.49. Flexibility enabled by packaging materials
- 6.50. Combination
- 6.51. Improvements of multiple components done by BattFlex
- 6.52. AMO's flexible and bendable batteries: innovations
- 6.53. AMO's flexible and bendable batteries: specifications
- 6.54. AMO's flexible and bendable batteries: safety test
- 6.55. AMO's flexible and bendable batteries: Product flow chart
- 6.56. Device-Design-Derived Flexibility
- 6.57. Cable-type batteries
- 6.58. Cable-type battery developed by LG Chem
- 6.59. Battery on wire
- 6.60. Huineng (Tianjin) Technology Development
- 6.61. Large-area multi-stacked textile battery for flexible and rollable applications
- 6.62. Stretchable lithium-ion battery — use spring-like lines
- 6.63. Foldable kirigami lithium-ion battery developed by Arizona State University
- 6.64. Flexible electrode assembly
- 6.65. Fibre-shaped lithium-ion battery that can be woven into electronic textiles
- 6.66. Stretchable batteries that stick to the skin like a band-aid
- 6.67. Flexible Battery Patent Analysis
- 6.68. Flexible battery patent application and publication trend
- 6.69. Flexible battery patent top assignees
- 6.70. Flexible battery important companies
- 6.71. Flexible battery geographic territories
- 6.72. Flexible battery portfolio value distribution
- 7. PRINTED BATTERIES
- 7.1. Printed battery technologies

- 7.2. Zinc-based printed batteries
- 7.3. Printed battery layout
- 7.4. Component options of printed batteries
- 7.5. Materials/compositions for printed batteries in research
- 7.6. Typical construction and reaction of printed disposable battery
- 7.7. Players in printed battery industry
- 7.8. Research strategy for development of printed batteries
- 7.9. Printed Battery Case Studies
- 7.10. Printed batteries from Fraunhofer ENAS
- 7.11. Fraunhofer ENAS' printed batteries
- 7.12. Varta Microbattery/Varta Storage
- 7.13. SoftBattery® from Enfucell
- 7.14. Blue Spark batteries
- 7.15. FlexEL LLC
- 7.16. Printed battery from Printed Energy
- 7.17. Paper batteries from Rocket Electric
- 7.18. Zinergy
- 7.19. Liten CEA Tech: printed battery
- 7.20. Rechargeable ZincPoly™ from Imprint Energy
- 7.21. Imprint Energy's technology innovations and specifications
- 7.22. Flexographically printed Zn/MnO₂ battery
- 7.23. Screen printed secondary NMH batteries
- 7.24. Manufacturing Processes of Printed Batteries
- 7.25. Printing techniques
- 7.26. Descriptions of various printing techniques
- 7.27. Comparison of printing techniques
- 7.28. Throughput vs. feature size for typical printing processes
- 7.29. Advantages and disadvantages of printing techniques used for printed battery fabrication
- 7.30. Examples of production facilities
- 8. BATTERIES WITH OTHER VALUE PROPOSITIONS
- 8.1. Needle battery from Panasonic
- 8.2. Batteries with optical properties
- 8.3. Transparent components for batteries
- 8.4. Transparent battery developed by Waseda University
- 8.5. Grid-like transparent lithium-ion battery
- 9. OTHER LAMINAR AND FLEXIBLE ENERGY STORAGE
- 9.1. Laminar fuel cells
- 9.2. What is a capacitor
- 9.3. Comparison of construction diagrams of three basic types of capacitor
- 9.4. Supercapacitor
- 9.5. Electrolyte options for supercapacitors
- 9.6. Thin and flexible supercapacitor - PowerWrapper
- 9.7. Two product lines fill the power gap
- 9.8. Battery-like thin-film supercapacitor by Rice University
- 9.9. Printed supercapacitors
- 9.10. University of Southern California
- 9.11. Flexible, transparent supercapacitors
- 9.12. Biological supercapacitors for pacemakers
- 10. MATERIAL SELECTION
- 10.1. Main lithium producers and lithium sources
- 10.2. Cobalt - From ore to metal
- 10.3. Cathode materials for primary cells

- 10.4. Cathode materials for secondary cells
- 10.5. New cathode materials - FDK Corporation
- 10.6. Graphite for batteries
- 10.7. Anodes
- 10.8. Anode alternatives - other carbon materials
- 10.9. Anode alternatives - silicon, tin and alloying materials
- 10.10. Summary of the electrolyte properties
- 10.11. Liquid electrolytes
- 10.12. Types of polymer electrolytes
- 10.13. Solid-state electrolytes
- 10.14. Gel Electrolytes
- 10.15. Binders - aqueous vs. non-aqueous
- 10.16. Current collectors
- 10.17. Current collectors and packaging
- 11. APPLICATIONS
- 11.1. Introduction to Applications
- 11.1.1. Applications of battery with new form and structural factors
- 11.1.2. Power range for electronic and electrical devices
- 11.2. Wearables: Stagnating?
- 11.2.1. The growth of wearables
- 11.2.2. Changes towards wearable devices
- 11.2.3. Batteries are the main bottleneck of wearables
- 11.2.4. Wearables at different locations of a human body
- 11.2.5. Wearables: smart watch, wristband and bracelet
- 11.2.6. Battery requirements
- 11.2.7. Wrist-worn application examples with flexible batteries
- 11.2.8. Ankle/foot-worn application examples
- 11.2.9. Head/eye-worn application examples
- 11.2.10. Electronic apparel & glove and textiles
- 11.2.11. Military
- 11.2.12. Other wearable application examples
- 11.2.13. Summary and conclusions for wearable applications
- 11.3. Medical and Cosmetic: Huge Opportunities?
- 11.3.1. Mobile healthcare: Huge growth potential
- 11.3.2. Cosmetic skin patches
- 11.3.3. Iontophoresis for cosmetics
- 11.3.4. Cardiovascular monitoring patch
- 11.3.5. Wireless inpatient monitoring
- 11.3.6. Temperature monitoring
- 11.3.7. Life Science Technology
- 11.3.8. Conformal displacement sensor
- 11.3.9. Medical skin patches - the dark horse
- 11.3.10. A list of increasing number of medical skin patch products
- 11.3.11. Medical implants
- 11.4. Consumer Electronics: What Next?
- 11.4.1. Future trend in battery for consumer electronics
- 11.4.2. Flexibility: Big giants' growing interest
- 11.4.3. Thinness is still required for now and future
- 11.4.4. Slim consumer electronics
- 11.4.5. New market: Thin batteries can help to increase the total capacity
- 11.4.6. Will modular phones be the direction of the future?
- 11.4.7. Thin and flexible supercapacitor for consumer electronics

- 11.5. From Sensors to Internet of Things
 - 11.5.1. Something new vs Renamed world of mobile phones
 - 11.5.2. Internet of Things
 - 11.5.3. Batteries for IoT
 - 11.5.4. Power supply options for WSN
 - 11.5.5. Rod-shape battery - examples
 - 11.5.6. Novel examples of thin batteries in IoT devices
 - 11.5.7. Golf sensor patch powered by printed battery
 - 11.5.8. Smart device powered by solid-state battery
 - 11.5.9. Thoughts about thin and flexible batteries in novel devices
 - 11.5.10. Maintenance-free wireless power for the IoT: Ready or not?
 - 11.5.11. Micro-batteries integrated with energy harvesting devices
 - 11.5.12. Real time clock backup, SRAM backup and microcontroller (MCU)
 - 11.5.13. RFID sensors/ tags with thin batteries
 - 11.5.14. Examples of thin batteries used in RFID tags/ sensors
- 11.6. Smart Packaging and Advertising
 - 11.6.1. Smart packaging and advertising examples
 - 11.6.2. Audio Paper™ developed by Toppan Printing
 - 11.6.3. Case studies of power for smart packaging
- 11.7. Powered Smart Cards
 - 11.7.1. Where will the powered smart cards go?
 - 11.7.2. Arrangement of batteries in smart cards
 - 11.7.3. Battery alternative solution
 - 11.7.4. Changes in smart card field
- 11.8. Other Markets
 - 11.8.1. Application examples
 - 11.8.2. How about printed battery for other disposable applications
- 12. FAILURE STORIES
 - 12.1. Companies that have stopped trading
- 13. END-USER INTERVIEWS
- 14. GLOSSARY AND ABBREVIATIONS
 - 14.1. Glossary
 - 14.2. Abbreviations
- 15. GLOBAL PLAYERS
 - 15.1. List of global players with descriptions
- 16. COMPANY PROFILES
 - 16.1. 24M
 - 16.2. BattFlex/Enerol nanotechnologies
 - 16.3. Blue Spark
 - 16.4. BrightVolt
 - 16.5. Cymbet
 - 16.6. Enfucell Flexible Electronics
 - 16.7. FlexEI
 - 16.8. Fraunhofer ENAS, Technische Universitaet Chemnitz
 - 16.9. Front Edge Technology
 - 16.10. FullRiver Battery New Technology
 - 16.11. Hitachi Zosen Corporation
 - 16.12. Huizhou Markyn New Energy
 - 16.13. Imprint Energy
 - 16.14. Ilika
 - 16.15. Jenax
 - 16.16. Johnson Battery Technologies

- 16.17. Kalptree Energy
- 16.18. Lionrock Batteries
- 16.19. MIT
- 16.20. Paper Battery Company
- 16.21. PolyPlus/Ohara
- 16.22. Prelonic Technologies
- 16.23. ProLogium
- 16.24. Printed Energy
- 16.25. Rocket Electric
- 16.26. Sakti3
- 16.27. STMicroelectronics