EE607: MICROELECTROMECHANICAL SYSTEMS (MEMS)

Technology methods and physical principles of MEMS including survey of current MEMS

- Instructor: Prof. Eun Sok Kim (eskim@usc.edu, PHE 602, 740-4697)
  - Office Hours: Monday and Thursday 5:00-5:50
- Class Time and Place: Friday 9:00 – 11:50am in VHE 206
- Textbook: My lecture notes from http://blackboard.usc.edu/

  The following books may be helpful on some specific topics of the course.
  - Micromachined Transducers Sourcebook by Gregory Kovacs
  - Fundamentals of Microfabrication by Marc Madou
  - Introduction to Microelectromechanical Systems Engineering by Nadim Maluf
  - Microsystem Design by Stephen Senturia
  - RF MEMS Theory, Design and Technology by Gabriel Rebeiz
  - Microsensors, MEMS and Smart Devices by Julian Gardner, et al.
  - Foundations of MEMS by Chang Liu

Additional Course Information

- Other References:
  - IEEE/ASME Journal of Microelectromechanical Systems
  - Journal of Micromechanics and Microengineering
  - Sensors and Actuators Journal (Elsevier Sequoia Publishing, Switzerland)
  - Sensors and Materials Journal (Japan)
  - Sensors Magazine
  - International Conference on Solid-State Sensors and Actuators (Transducers Conf.)
  - Solid-State Sensor & Actuator Workshop, Hilton Head Island, SC (Hilton Head Workshop)
  - Micro Electro Mechanical Systems (MEMS) Workshop/Conference.

- Midterm Exam: *Tentatively* March 9 (Friday) in VHE 206
- Final Exam: 8:00 – 10:00am on May 4 (Friday) in VHE 206

Course Contents and Grading

- Week 1: Introduction to MEMS
- Weeks 2 - 4: Micromachining
  - Bulk and Surface Micromachining, Plasma and Laser Micromachining, LIGA, etc.
- Weeks 5 & 6: Microactuators (electrostatic, electromagnetic, piezoelectric, etc.)
- Weeks 7 & 8: Optical and RF MEMS
  - Projection display, optical cross connect, etc.
  - FBAR, RF switches, micromechanical resonators, etc.
- Weeks 9 - 11: Mechanical Theories and Inertial/Mechanical MEMS
  - Resonance, Solid Mechanics, Beam and Plate Theories
  - Accelerometers, Gyroscopes and Pressure Sensors
- Weeks 12 & 13: Materials Properties (and Deposition Techniques) of Thin Films
  - Polysilicon, Low-Stress Silicon Nitride, AlN, PZT, etc.
- Week 14: Acoustic MEMS
  - Microphones, SAW/BAW Sensors, Ultrasonic Transducers, etc.

- **Grading:** One Midterm Exam: 30%, Term Paper & Oral Presentation: 30%, Final Exam: 40%. Homework will be assigned, but not graded.
  - All exams are open books and notes.

TERM PAPER

- Literature review on one of the topics listed in pp. 6-7 of this handout.

- DATES: March 23 (Fri.): Abstract due at the start of the lecture.
  April 20 (Fri.): Term paper due at the start of the lecture.
  April 27 (Fri.): Oral presentations in class.

- TERM PAPER FORMAT:

  Cover page: Name, title of paper, and abstract which highlights the interesting results, significance of the research, novelty of approach, difference from existing theory or data, verification with experiments, applications, numerical examples, etc.

  Text: Not more than 2,000 words of text expanding on the abstract/summary. Do a "word count" on the text, and show the number at the end of the text. List key references.

  Figures: Unlimited number of figures with descriptive captions.

  Appendices: Any number of pages of appendices may be attached, though not encouraged. Here, you may show long derivations of equations, extensive review of literature, (additional) examples and explanations.

Term Paper Grading

- GRADING: 60% on technical content and 40% on written and oral presentation

- The technical content includes
  - breadth (a minimum of seven quality papers) and depth of coverage
  - usefulness of the review
  - correctness of physics, mathematics, technical reasoning, etc.

- The presentation includes
  - clarity of oral presentation including slide preparation, mechanics.
  - effective classification/formatting and grammatical correctness of writing
  - effectiveness in showing the usefulness, significance, or accuracy of the results/review: effective use of figures, examples, etc.

- Plagiarism will be *severely* penalized!
  - The instructor knows it when he sees it.

Potential Term Paper Topics

- Compare various sensing techniques (piezoresistive, piezoelectric, capacitive, etc.) that are compatible with MEMS processing
  - signal-to-noise, complexity of interface electronics, power consumption, DC response, temperature sensitivity, sensitivity drift, etc..
- Investigate potentially significant applications (e.g., bioassay, total chemical/biological analysis on chip, etc.) of microfluidic systems using micropumps, microvalves, microchannels, etc.
- Investigate the advantages and disadvantages (along with limitations and potential solutions to the limitations) of electrostatic, electromagnetic, *or* piezoelectric actuation for MEMS (either a single device *or* an array of 100,000), addressing the following issues.
  - dynamic range, power consumption, frequency response, IC-process compatibility, long term reliability, needed drive voltage, amplitude of motion
- Compare various inertial sensors: cost, minimum detectable signal, dynamic range, etc.
- Compare oscillators (for timing applications) based on quartz and silicon: cost, temperature stability, quality factor, aging, etc.
- For fiber-optic switching network (e.g., for LAN), compare various optics-to-optics switching techniques (including MEMS techniques) for signal routing.

Potential Term Paper Topics, Continued

- Review one of the MEMS commercial successes listed below, making sure that you present competing (or existing) technologies and addressing why the MEMS give winning edge in the market places. Note that I do not list TI's DPL and Analog Device's accelerometers, though they are MEMS commercial successes, because the students of the previous years tended to download information from the companies' web sites without going through a rigorous literature survey.
  - RF Front-end Filters Based on Film Bulk Acoustic Resonators
  - MEMS Microphones
  - MEMS Gyroscopes
- Compare piezoelectric ZnO, AlN and PZT films for a specific application (e.g., RF front-end filtering, camera autofocus, acoustic sensing, etc.).
- Investigate any of the following for MEMS applications.
  - nanowires, 2D materials, or any unique material/structure of your choice.
  - MEMS application requires the fabrication techniques to be applicable to at least 3" wafer. Low processing temperature is preferred, but not required.
- Choose a specific application (e.g., pressure sensing in automobile engine, human-machine interface, wearable device, virtual reality, internet of things, etc.), and investigate some viable MEMS approaches.
- Choose any topic of your choice that is based on the course materials.

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions/. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct/. Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu/ or to the *Department of Public Safety* http://capsnet.usc.edu/department/department-public-safety/online-forms/contact-us. This is important for the safety whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. The *Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage sarc@usc.edu describes reporting options and other resources.

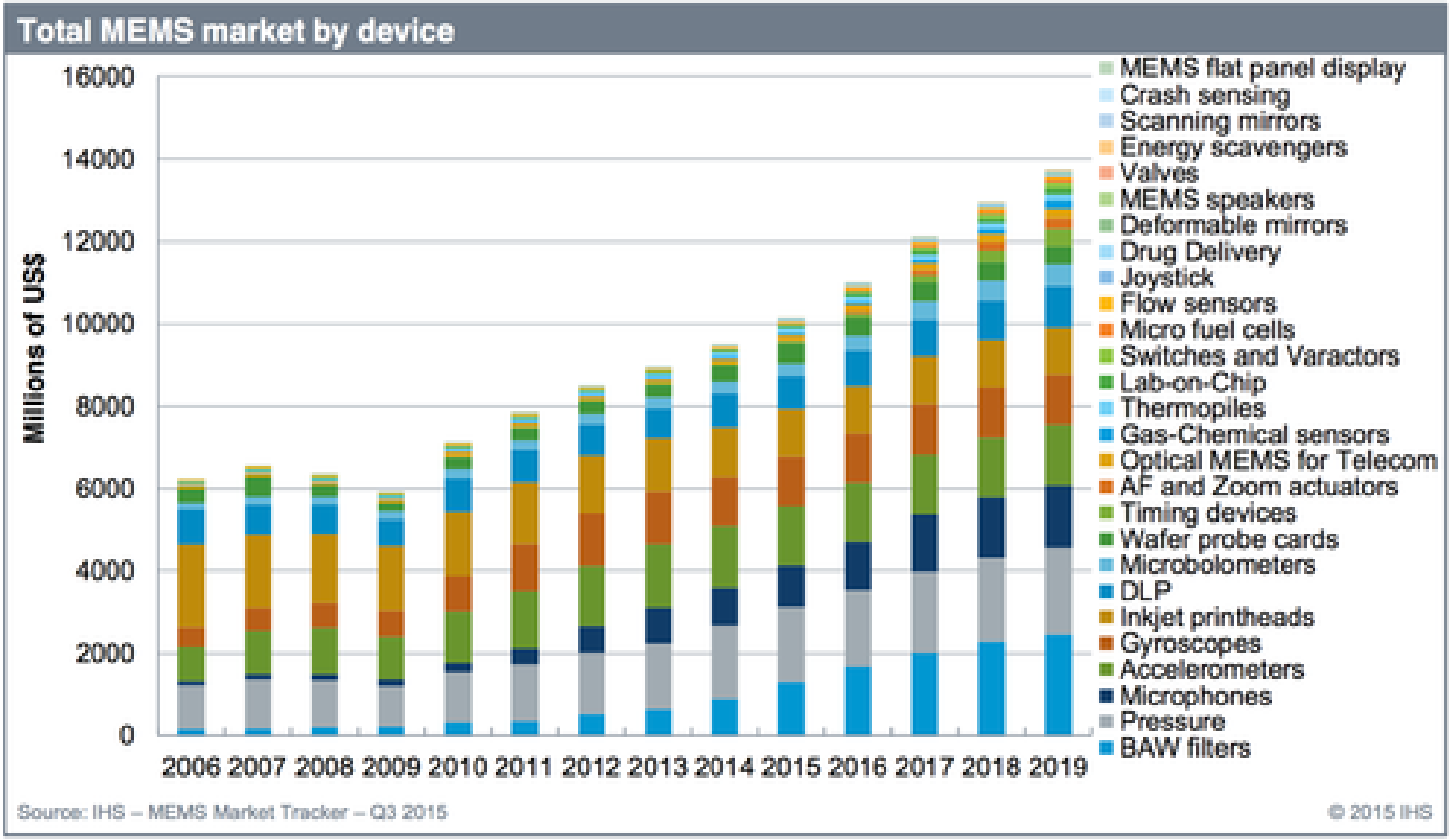
Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. The *Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.htmlprovides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* http://emergency.usc.edu/will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.

Diversity Statement

- The diversity of the participants in this course is a valuable source of ideas, problem solving strategies, and engineering creativity. I encourage and support the efforts of all of our students to contribute freely and enthusiastically. We are members of an academic community where it is our shared responsibility to cultivate a climate where all students and individuals are valued and where both they and their ideas are treated with respect, regardless of their differences, visible or invisible.

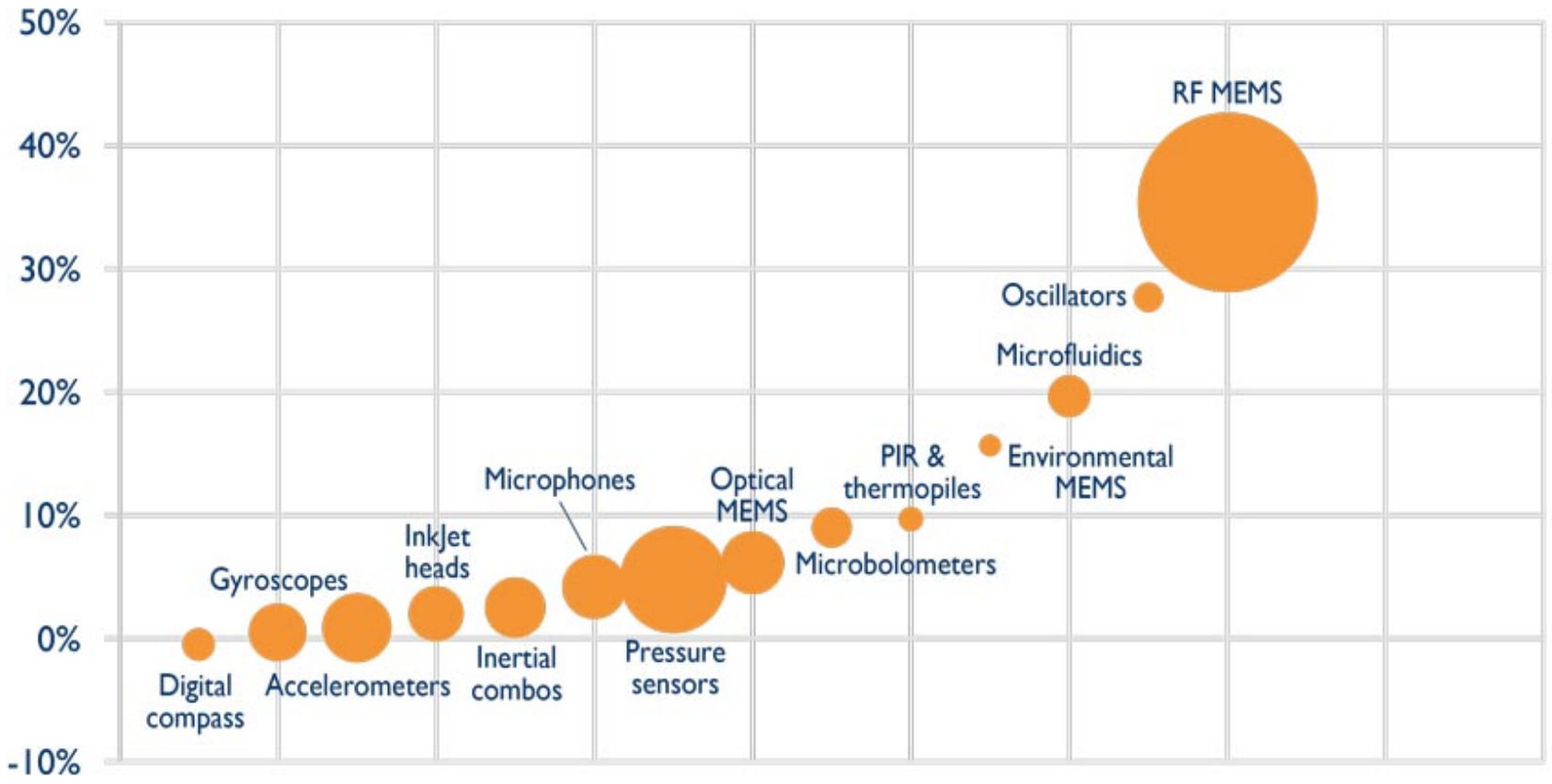
MEMS Market by Device – Q3 2015



2017-2022 MEMS CAGR for the different MEMS devices

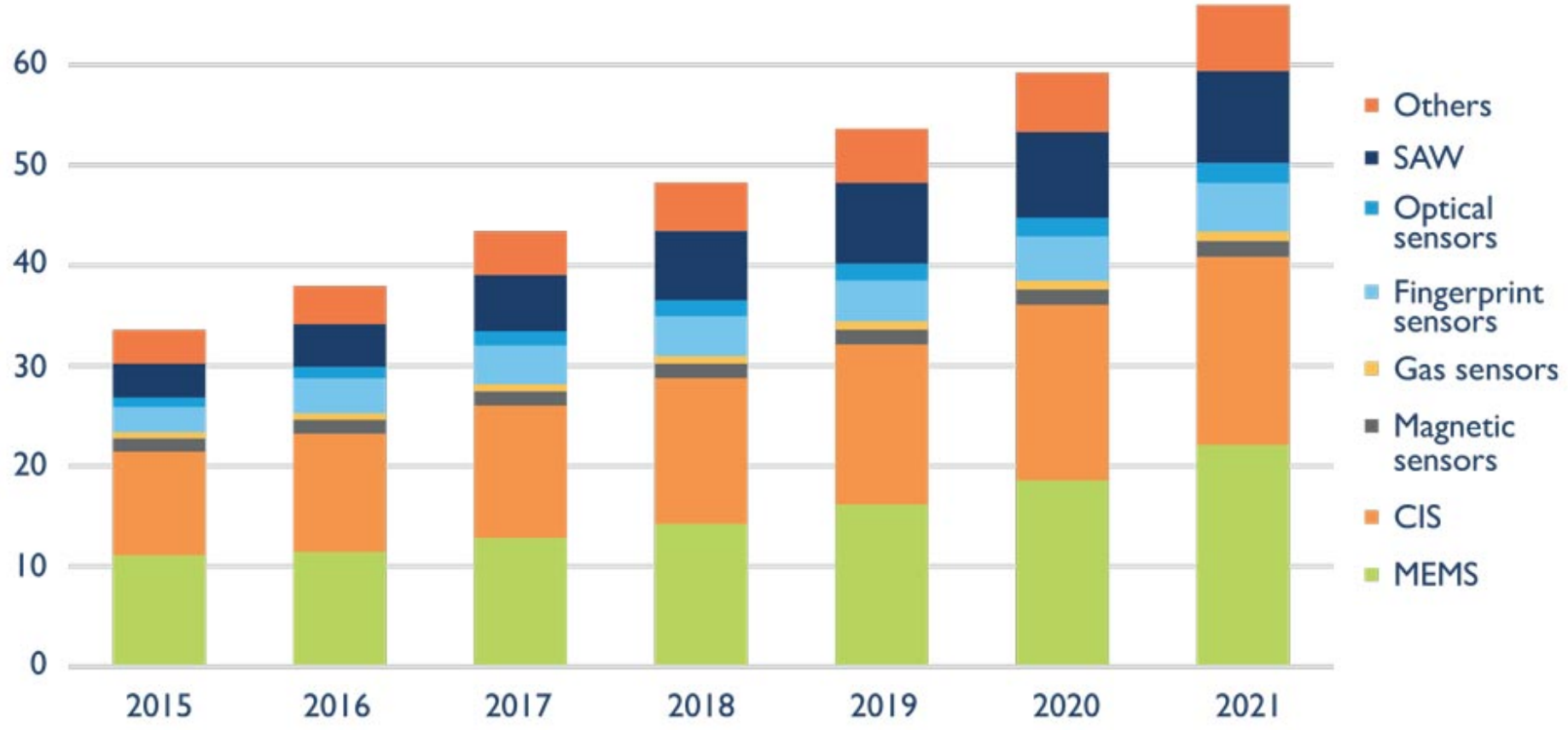
(bubble sizes are proportional to 2022 market size in M$)

(Source : Status of the MEMS Industry 2017, June 2017, Yole Développement)



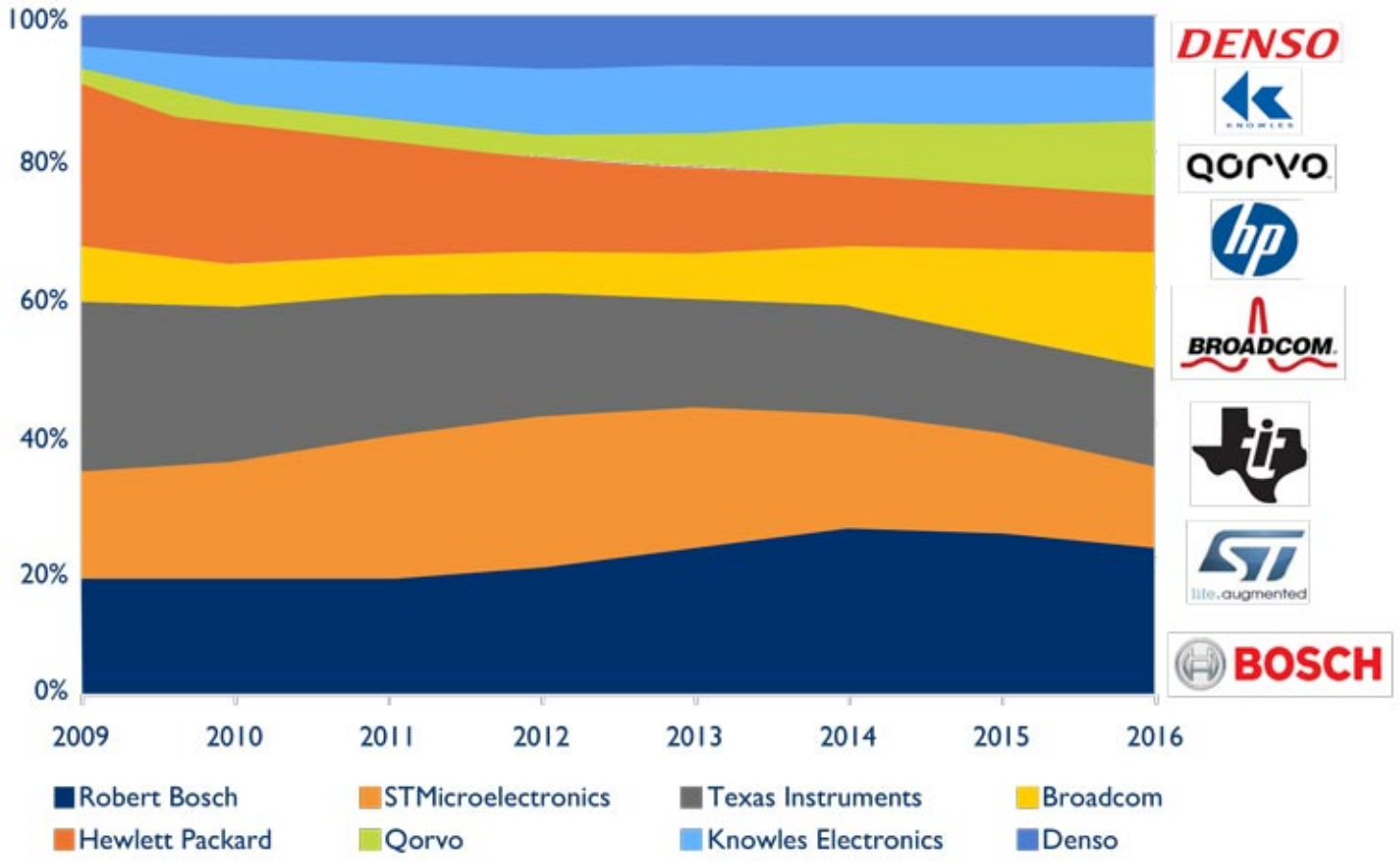
MEMS and sensors revenue market in B$

(Source : Status of the MEMS Industry 2017, June 2017, Yole Développement)

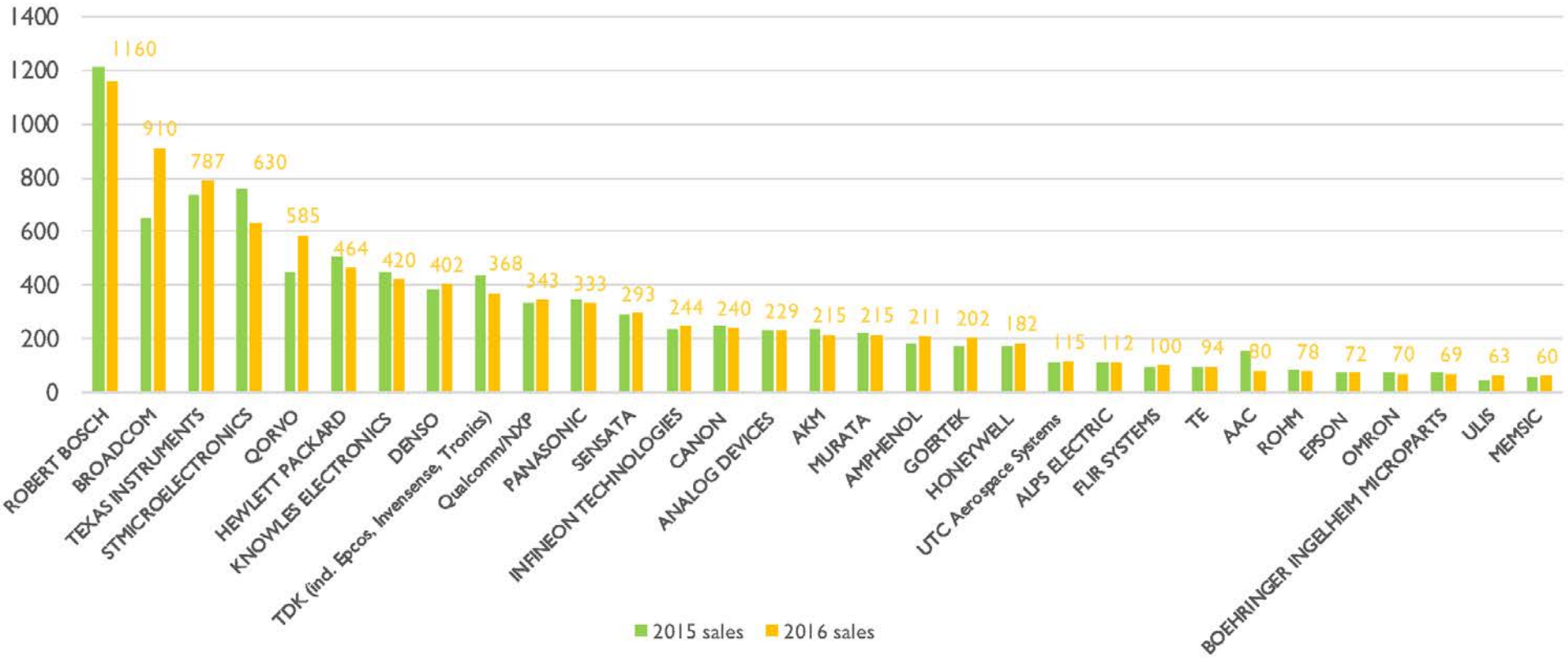


Relative market share history for the top eight MEMS players

(Source : Status of the MEMS Industry 2017, June 2017, Yole Développement)



Top 30 MEMS Companies by Revenue ($M) in 2016



Commercial MEMS

- MEMS Accelerometers
  - Mobile phones for human machine interface, wearable devices, etc.
  - Automotive air bag deployment and electronic stability program (ESP)
- MEMS Gyroscopes
  - Mobile phones (human machine interface), inertial navigation, etc.
  - Automotive ESP
- Pressure Sensors
  - Mobile phones
  - Industrial, medical and automotive instrumentation
- MEMS Microphones (for mobile phones)
- Optical MEMS
  - Deformable mirror array for projection display and flat panel display
- RF MEMS
  - Film Bulk Acoustic Resonators for RF-front end filters for mobile phones
  - RF switch for tunable capacitor and automatic test equipment
  - Silicon micromechanical and piezoelectric MEMS resonator for timing
- Ink-jet Print Head
- Internet of Things, Wearable Technology

MEMS Technology and Systems

- Advantages
  - Miniaturization
  - Microelectronics (i.e., Integration with IC Circuits)
  - Multiplicity (e.g., array of 300,000 pixels)
  - Mass Manufacturability due to Batch Processing

- Commercially Successful MEMS
  - TI's Digital Light Processing (DLP) for Projection Display
  - MEMS Accelerometers and Gyroscopes
  - Film Bulk Acoustic Resonators (FBAR) for RF Front-end Filtering
  - MEMS Microphones

- Challenging, but exciting!!!
  - multi-disciplinary
  - enabling for product differentiation
  - impactful
  - open-ended