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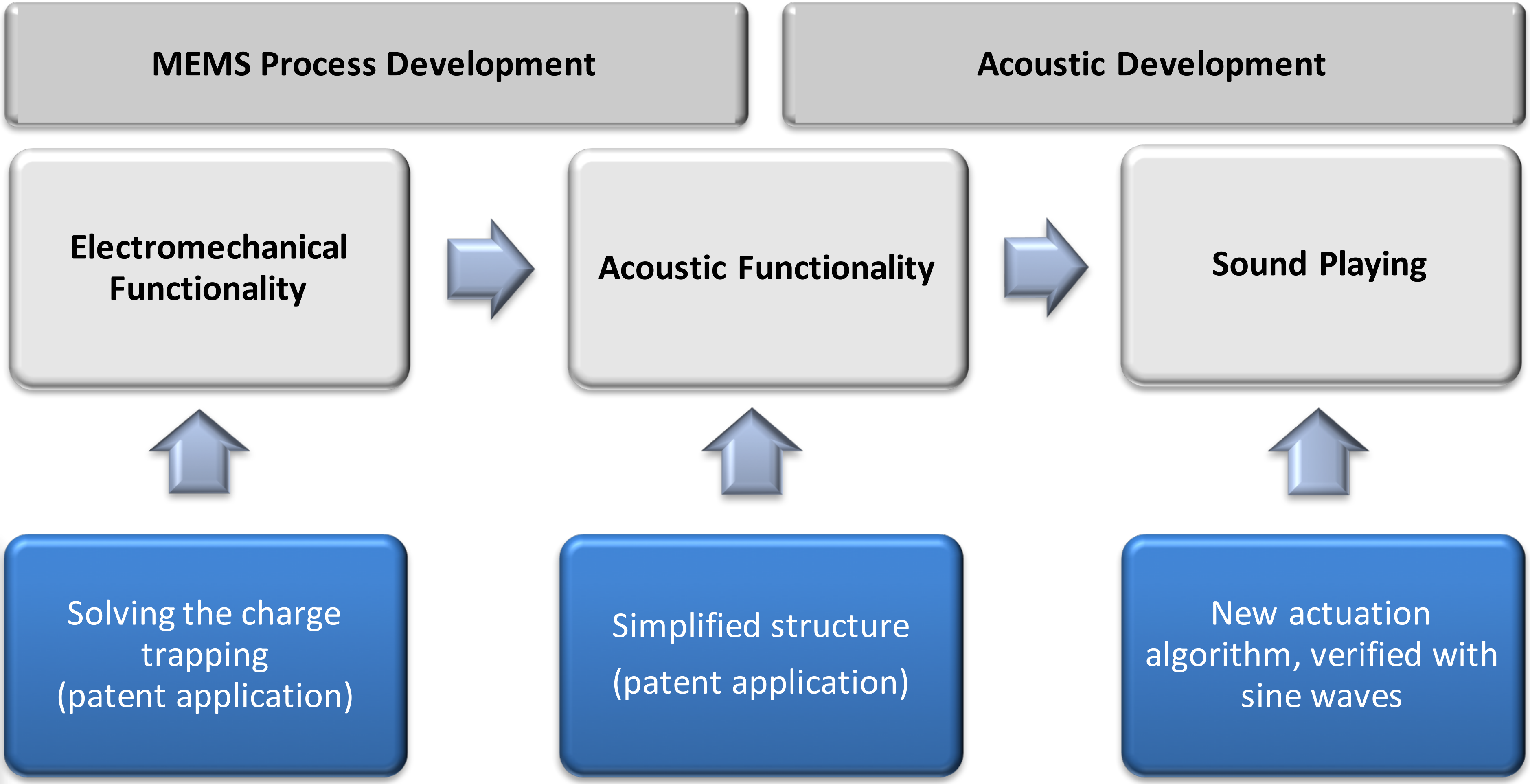
Breaking the Barriers of Sound

EGM – AP Status Summary
21/12/2018

3 outstanding breakthroughs



Breakthrough 1 – Solving the stiction issue

- **The Problem**
  - To achieve proper sound reconstruction our elements must begin and complete movement within a few microseconds (a millionth of a second).
  - To achieve such operational accuracy and stability the devices must respond to electrical commands with sub-microsecond precision.
  - There are well known effects inherent to electrostatically actuated MEMS devices that adversely and unpredictably impact the device's electro-mechanical response. The most dominant (in our case) is charge trapping, which causes stiction and slow release.
  - Furthermore, the relatively larger amplitude required by our devices demands the use of higher voltages compared to other MEMS devices. This, in turn, increases the severity and unpredictability of such undesirable effects
  - **Summary: effective suppression of charge trapping (that is intrinsic to electrostatically driven MEMS actuators) is critical to achieve operational functionality and stability for MEMS devices**

Breakthrough 1 – Solving the stiction issue

- **The Problem (cont…)**
  - Charge trapping is related to dielectric layers.
  - Dielectric layers are required to prevent electrical shorts when the plates come into contact with each other
  - Under normal operation electrical charges
    - a) accumulate on the surface of the dielectric materials
    - b) penetrate into and remain trapped in the dielectric layers.
  - Accumulated charges attract the opposite surface and slow or prevent the release of the membrane.
  - The "amount" of charges on and in the dielectric layer is influenced by many variable factors (voltage, cycle frequency, speed, timing, materials, humidity, temperature etc…)
  - Summary: It is critical to incorporate effective mechanisms to dissipate such charges.

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Breakthrough 1 – Solving the stiction issue

- **The Problem (cont…)**
  - There are a number of available anti-stiction coatings and other approaches developed and used by the industry to avoid and dissipate surface and trapped charges.
  - AP tried to implement several "off-the-shelf" solutions but the combination of higher operation voltages and repeated impacts caused all these solutions to fail.
  - In the past 18 months AP focused primarily on one such approach: adding a dissipation layer atop the dielectric. Extensive development and testing ultimately led us to realize that:
    - The process "fabrication window" is extremely narrow. The complexities involved in fabrication and fine-tuning of the dissipation layers proved to be insufficiently repeatable or reliable for our particular needs.
    - The "operational window" is very narrow– changing playing conditions often exceeded the dissipation capabilities of the device.

Breakthrough 1 – Solving the stiction issue

- **The Solution**
  - The company conducted a very deep forensic examination and found that all known approaches were likely to be insufficiently compatible with our requirements.
  - As part of this investigation, the company developed proprietary measurement techniques that allowed direct imaging of charging and dissipation properties of dielectric layers. These techniques allowed us to “see” electrons as they move in and out of the investigated layers.
  - The company re-assessed the problem and devised 3 different approaches to supress the adverse effects that are specific to our device

Breakthrough 1 – Solving the stiction issue

- **The Solution**
  - All 3 approaches were fabricated, tested and **all 3 proven to work**
  - One approach, in particular, was selected as it not only proven to be robust and effective, it was also the easiest to implement. As an added benefit, this approach reduced the layer count and number of processes (and therefore the cost) required to fabricate our chips.
  - The approach has so far proven itself under the most extreme ”real playing conditions”.
  - **We have (so far) achieved nearly 100,000,000,000 repeatable cycles without failure.**
  - Patents have been filed as the approach is potentially applicable across a wide variety of applications throughout the MEMS industry.

Breakthrough 2 – Simplified Structure

- During development of our full structures, we regularly build partial structures to optimize and test specific features of the device. Such simplified structure designs were used to expedite the development and test of the various anti-stiction solutions.
- Several months ago, we used such simplified structure to begin acoustic characterization of the device.
- Contrary to known convention (and our own estimates) the devices produced significant sound pressure!
- New driving algorithms had to be developed (i.e invented) to take advantage of the acoustic properties of the simplified structure.

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Breakthrough 2 – Simplified Structure

- Wafers and algorithms were fabricated and developed to further explore the characteristics of this "simplified structure design".
- The recently received wafers have so far proven to provide exceptional performance in particular in generating low frequencies (below 100Hz).
- As the terminology suggests, once proven such structures are far easier and cost far less to fabricate.
- There are certain performance differences between the simplified and full structures, (e.g. higher power consumption for the simplified structure). The company's intention is to introduce both options to the market and make our offering more appealing to a wider range of applications.

Breakthrough 3 – Sound (Playing)

- Resolving operational stability enabled the company to make great strides advancing the playing capabilities of the devices.
- The Company mapped the acoustic performance of single pixels as well as groups of various sizes.
- These measurements revealed and confirmed a few important attributes of our structures:
    - The moving pixels produce acoustic energy at a very wide frequency range (sub-sonic to ultrasonic).
    - The superposition of multiple pixels working together behaves as we expect.
- Taking advantage of these characteristics required development of new driving algorithms.

Breakthrough 3 – Sound (Playing)

- The Company demonstrated the acoustic performance of the device using sine waves (at any desired frequency). As every acoustic professional will attest, sine waves are the building blocks required for playing any sound.
- **Early results are unprecedented** - reproducing frequencies below 100Hz! (by comparison the very best conventional speakers of similar sized have a lower limit around 800Hz or 3 octaves above ours).
- The Company is currently integrating the new algorithms into the full signal processing suit. Once completed, the device would play any desired sound (i.e music, speech, ultra-sound etc.).

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Next Steps

- Delivery balance of development wafers during January / February
- Complete testing and algorithm adjustment and introduce / demonstrate music play
- Complete last process steps as to allow chip packaging
- Engage fabricators in transition to mass production

Questions?