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Recent developments in Microelectromechanical systems (MEMS)

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Abstract: Advanced manufacturing technologies of MEMS have allowed their integration in new fields of industry, for example wearable sensing devices. This opened the way to find advanced medical applications like human motion analysis, health monitoring, and activity recognition, as well as numerous others, including space applications, automotive sensors and precision farming. The limited form factor leads to many interesting research angles, and some of the most recent ones will be discussed in this article. Among others, current state of research into creating world's first MEMS electron microscope, as well as an innovative method of hardware development of wearable MEMS will be described, which provide advanced sensing, communication, and processing capabilities, while ensuring limited power consumption and adequate ergonomics. Furthermore, a brief analysis of the current state of the MEMS field will be provided, based on recent research and developments.

Keywords: MEMS, development, advanced applications, manufacturing

1. INTRODUCTION

The ongoing rise in wearable sensors industry is in large part driven by demand for features allowing for health and fitness monitoring and improved user interface. Starting with smartphones and continuing into wearable technologies, industry moved away from implementing simple sensors and progressed into developing more sophisticated combo-sensors, encompassing multiple sensing devices in one frame. The need for compact dimensions of those combo-sensors, dictated by their purpose as parts of wearable technology, meant that development of such devices required production technologies used for MEMS. Furthermore, the already existing microelectromechanical systems also found use in wearable devices alongside non-MEMS based sensors. The types used in wearables are MEMS and non-MEMS based sensors for user interfaces, health and environmental sensors and, of course, motion sensors. Motion sensors are the dominant technology in the wearables segment and include accelerometers, magnetometers, pressure sensors, gyroscopes and combo motion sensors. MEMS sensors for user interfaces include devices like microphones, proximity sensors and displays. Health sensors encompass pulse, pulse-oximeters, hydration and skin temperature sensors. Environmental sensors include humidity, temperature and ultraviolet components.

2. PRODUCTION TECHNOLOGIES

To large extent production of wearable sensors is based on existing MEMS production methods used by different companies. Those include:

Surface micromachining is the fabrication of micromechanical structures through deposition and etching of thin structural and sacrificial films. Complex structures like encapsulated resonators or linkages as well as simpler microstructures like beams or membranes can be fabricated on top of a silicon substrate. Among main features of the surface micromachining technology are small dimensions and the possible integration of micromechanics and microelectronics on the same chip. By using a VLSI compatible batch processing, low cost microstructure fabrication can be achieved for high volume applications. It is a technology very popular in applications for fabricating MEMS, with a number of variations of how it is performed, depending on the materials and etchant combinations used. The common sequence starts with the deposition of a thin-film to act as a temporary mechanical layer (sacrificial layer) onto which the actual device layers are built. CVD and thermal silicon oxide films are often used as sacrificial layer, which can be etched with high selectivity against silicon using hydrofluoric acid. Next, thin-film device layer of material, referred to as the structural layer, is deposited and patterned, followed by the removal of the temporary layer which allows the structural layer to move.

Deep reactive ion etching or **DRIE** is a relatively new fabrication technology that has been widely adopted by the MEMS community. It allows for very high aspect ratio etches to be performed into silicon substrates. The etch can have the depth of hundreds or even thousands of microns and sidewalls of the etched holes are nearly vertical. This method uses a high density plasma to alternately etch the silicon and deposit an etch resistant polymer layer on the sidewalls. The protective polymer layer is deposited on the sidewalls as well as on the bottom of the etch pit, but the anisotropy of the etch removes the polymer at the bottom faster than from the sidewalls. The sidewalls are not perfected or optically smooth, a characteristic washboard or scalloping pattern can be seen under SEM inspection. The etch rates on most commercial DRIE systems varies from 1 to 4 microns per minute.

LIGA is a high aspect ratio micromachining technology, a German acronym for "**LI**thographie **G**alvanoformung **A**dformung." It is primarily a non-silicon based technology, requiring the use of synchrotron generated x-ray radiation. The basic process starts with the cast of an x-ray sensitive PMMA onto the substrate. An special mask is used for the selective exposure of the PMMA to the x-rays. The PMMA is then developed with extremely smooth and almost perfectly vertical sidewalls. The penetration depth of the x-ray radiation into the PMMA layer is considerable and allows exposure of very thick PMMA layers, up to and exceeding 1 mm. After the development, the patterned PMMA serves as a mold and is placed into an electroplating bath, where metallic material is plated into the open areas of the PMMA. The PMMA is then removed, leaving the metallic microstructure. LIGA is a relatively expensive process, since it requires a special mask and a synchrotron radiation source for the exposure. A cost reducing variation of the process is to reuse the fabricated metal part as a tool to imprint the shape of the element into a polymer layer to create a new mold, followed by electroplating of metal into the polymer mold and removal of the polymer.

This sequence of steps eliminates the need for a synchrotron radiation source each time, significantly lowering the cost of the process.

3. MEMS ELECTRON MICROSCOPE

Researchers from Wrocław University of Science and Technology are creating world's smallest electron microscope using MEMS technologies. Team lead by dr. Anna Górecka-Drzazga plans to build a functioning electron microscope on a single chip with the dimensions of a few centimeters. This type of research is not new, as many universities around the globe had already attempted to recreate elements of microscopes as MEMS, but until now developing a fully functioning device has never been accomplished. While most parts were relatively easy to produce using current methods, the biggest obstacle until now was the need to create high vacuum in a small space for the miniature electron microscope to work. This problem, however, was recently solved by researchers from Wrocław, when they created world's first functioning MEMS ion-sorption pump, capable of creating high vacuum in the miniscule work chamber of the microscope. This opened the way to combining all elements into a fully operational device. Researchers plan is to design all the components in the form of MEMS devices, which will then be integrated them into a single chip. For this purpose they plan to use the technique of forming spatial structures in silicon and glass. The source of electrons will be a silicon cathode coated with carbon nanotubes, to which an electron optical column made of several electrically isolated silicon electrodes will be attached. They will control the focus of the electron beam on the sample. Unlike classic electron microscopes, MEMS electron microscope will be portable and more affordable. The initial main focus of the device is to be used in medical research, where it can be utilised for diagnosing cancer, among other things.

4. INNOVATIVE PRODUCTION METHOD

Apart from established production methods, a new and innovative one was developed by company in california called mCube Inc. They produce what is widely recognized as the world's smallest accelerometer, with dimensions of 1-by-1 millimeter. To create this impressive 1-by-1 millimeter die size, mCube is using a special 8-inch wafer fabrication facility that usually produces standard CMOS chips. In this case, however, it switches to MEMS processing steps in the middle of the line, enabling a MEMS+CMOS chip to be created on a single production line. The mCube process first fabricates a complementary metal oxide semiconductor application specific circuit on the bottom, then grows the mechanical MEMS material atop the CMOS. This step is followed by etching of high-aspect-ratio bars perforated by three micron vias for the accelerometer. This results in no bonding wires to pick up RF interference or come loose, and much less parasitic capacitance than with the usual two-die solution. According to the company it is the world's only monolithic MEMS+CMOS single-chip sensor in production. It offers accelerometers, magnetometers and soft gyroscopes (combining its accelerometer chip with a magnetometer)

5. ADVANCED APPLICATIONS

MicroVision is the creator of PicoP® scanning technology, an ultra-miniature laser projection and imaging solution based on the laser beam scanning methodology. This platform approach for advanced display and imaging solution means that it can be adapted to a wide array of applications and form factors. MicroVision is currently working on MEMS technology that include their previously invented ideas. MEMS are used in automotive industry because it requires more sensitive data sensors which are in experimental phase.

Its name is advanced driver assistance systems (ADAS). This technology is strictly synced with Head-up displays (HUDs) for improved safety alerts. Function of those technologies is to keep attention of the driver on the road and for him to see the date from ADAS on HUD. Here is also present the third technology of laser beam scanning (LBS). LBS use the MEMS technology as crucial part. A MEMS scanning mirror is the core part of our laser beam scanning (LBS) display technology which can, together with relay optics, be used to build and realize HUD applications. The same MEMS scanning mirror technology acts as a sensor for ADAS applications. The difference is the use of IR lasers for sensing whereas RGB lasers are used for display. For old school manual-driving, information relayed to the driver with HUD may have included speed, gear and RPM, and GPS navigation information. For ADAS assisted driving, there will be additional information relayed to the driver, such as an adaptive cruise control state, lane departure warning, blind spot warning, obstacle ahead alert, and traffic signs.

The MIPI Sensor Working Group, defines a standardized sensor interface to unify a fragmented sensor industry. It is chartered to develop a flexible interface that enables interface compatibility between vendor's sensor solutions; reuses existing interfaces when needed; provides value to adopters and sensor vendors; and can evolve to serve future sensor architectures and the market needs of the mobile, mobile-influenced and sensor industries, as well as complementary industries. Electronic industry is also struggling with rising demand for information that can be obtained through devices such as smartphones and wearables. In the beginning of 2017, the release of new sensor system interface is a big step forward. The MIPI I3C interface is a new standard that improves on the features of the two-wire I^2C, while maintaining backward compatibility. MIPI's new interface aims to standardize sensor communications by reducing the number of physical pins used in sensor system integration, and it supports low-power, high-speed communications. MIPI I3C is a chip-to-chip interface that can connect all sensors in a device to an application processor. It is implemented on a standard CMOS I/O using two wires, which drastically reduces device pin count and signal paths and facilitates incorporation of more sensors in a device. It achieves clock rates of 12.5 MHz and provides options for higher performance, high-data-rate modes. The release of MIPI I3C is a milestone because the specification unifies traditional sensor integration approaches to provide must-needed conveniences and system-level benefits for a broad range of applications.

Engineers expect its key uses to include sensor integration in smartphones, wearables, IoT devices, but the specification is very versatile and can also be used to integrate sensors in medical instruments, industrial equipment, all-in-one computers, TV remotes and other products. MIPI I3C supports numerous types of sensor components and functions, from mechanical and motion sensors to transducers and actuators and to environmental, biometric and health sensors, among others. It can also be used as a power management and control interface in certain types of devices.

MEMS Drive Inc. is a fabless semiconductor company that develops, manufactures and markets cutting-edge MEMS actuators. Products of this company targets hardware application in mobile imaging of portable electronics. Funded and supported by its customers in the cellphone camera market, MEMS Drive Inc. is at the forefront of this constantly evolving field. MEMS Drive is working on new application that is present in electronic industry, which is newly engineered actuator device maker with focus on optical image stabilization (OIS). Mechanism of this device is moving the image sensor in x-y plane in a very fast and precise way. This allows to compensate the undesired vibrations that cause image blur while taking a photo.

Currently available technologies only provide 2-axis compensation, where this device provide 3-axis compensation. This technology significantly enhances the OIS performance in mobile by allowing 3- axis (pitch, yaw, and roll axis stabilization). Competitors of MEMS Drive are moving the lens barrel, which means that they are limited to 2-axis compensation only. MEMS Drive actuator is using electrostatic comb drive instead of the voice coil motor (VCM), and because of that, this device has ultra-low power consumption.

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