Micro-windmills have the potential to be charging platforms to provide power in areas that it is not available. Photo Credit: University of Texas, Arlington

Micro-Windmills: From Lab to Market

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Micro-windmill, energy harvesting platforms help make sensors more power independent.

Not all design engineering ideas begin as sketches on a restaurant napkin. Some designs start in the labs at the most prestigious engineering schools around the world, such is the story of Jung-Chih (J.C.) Chiao and Smitha Rao’s micro-windmill that generates wind energy.

More than 11 years ago, Chiao, an electrical engineering professor at the University of Texas in Arlington [1], was focusing his research on micro-electro-mechanical systems (MEMS), when he and Rao had the idea of putting something moveable, like a windmill, on silicon chips.

“There were obvious reasons to do this,” says Chiao. “One was energy harvesting, because in most computers and electronics there is a lot of heat gradient, and we thought maybe we could use the design to harvest the airflow in the module system.

We could then take that harvested energy and use it as a fan to cool down the system like a computer cooling fan, but much smaller and more efficient.”

The team was using conventional silicon MEMS [2] fabrication techniques, so the silicon layer ended up being very thin. “Silicon is a very strong material, but at the same time, it’s very brittle with a micrometer thickness,” explains Chiao. “Anytime there was a very light wind, the wind turbine operated fine, but when the wind speed picked up, the silicon couldn’t take the force...
and shattered."

After several trials with no success, Chiao admitted that the team sort of gave up and didn’t revisit the idea until 2012 when they connected with Taiwan-based, company WinMEMS.

Back from the Dead

The WinMEMS CEO was a former classmate of Chiao’s, and after a class reunion, he explained to Chiao that he thought they could work together. WinMEMS uses different materials, such as nickel alloy, to create MEMS devices. Chiao explained how they started making very small surgical tools, micro gears, and micro inductors using WinMEMS’ fabrication process. “It wasn’t until the end of the design process for that project that my research associate, Rao, suggested we revisit the windmill idea using the materials from WinMEMS.”

No available literature or tools existed to help start the design process because WinMEMS’ fabrication procedures have not been standardized with respect to design rules, layout functions, and building blocks. Chiao and Rao only had intuition from the past twelve years of experience to help guide them through the design process.

“We had to think about how to make the blades moveable while keeping the main structure stable and robust while the wafers pass through harsh chemical and mechanical processes. We used micro-machining techniques with sacrificial layers to create a 3D structure from several plated layers of nickel alloy,” says Chiao. “In laymen’s terms, it’s like making a cake. We had five structural layers with four sacrificial layers in between. When the entire wafer was done with deposition, we soaked it in an etchant solution remove the sacrificial layers. 3D hinges and interconnects were formed to allow mechanical motion. There is no assembly required.”

This particular technique is new, but the basic principles are exactly the same as in MEMS fabrication, providing the advantages of low cost, mass production, wafer-scale batch manufacturing, and integration with complementary metal–oxide–semiconductor (CMOS) circuitry. However no commercial software has adopted this particular technique, Chiao and his team had to work from layers of 2D drawings, visualizing what it would look like in the 3D world.

“WinMEMS has developed devices used for integrated circuit probes that have displayed robustness, owning to mechanical elasticity in the alloy,” says Chiao. “In general, it has not been statistically demonstrated that it can be used for a long period of time in regards to the MEMS fields, so that is what we are focusing on now.”

Research That Has Never Been Done Before

Chiao and his team faced various challenges when designing micro-windmills, however they view them as research opportunities. First, the idea stems from research on something that has never been done before – no standards to consider, or previous designs to reference.

From a design perspective, this process is new to MEMS engineers, so there are no design or simulation tools to help with the fabrication process. The micro-windmills also involve electrical and mechanical design, so the team had to create a new modeling tool that would incorporate both.

“The second main challenge is the physics within the micro scale structures, the knowledge we have on large windmills does directly apply to what we’re trying to do. For example, in a bigger
windmills, we wouldn’t care too much about dust.

However, in a micro-windmill, dust could ruin the smaller parts,” says Chiao. “The deformation of blades from pressure in bigger windmills is also a lot different in micro-windmills, so we need to find solutions to these types of issues.”

The third challenge that the team faces is application. Chiao believes that the research will enable ideas for many different applications in wireless sensors for the Internet of Things [4], because the sensors can be placed at remote locations communicating with the Cloud with self-sustaining power. “If we invent just one thing for one particular application, then that's not a very good investment of our research in the university,” says Chiao.

Other challenges involve the researchers thinking about issues that they normally would not consider, such as mass production and cost. Chiao claims that the team is not solving these particular issues in a traditional fashion. “Traditionally, cost issues would be solved by looking at details in the manufacturing processes. We don’t really know what the manufacturing processes will be for these types of devices in the future, so we implement device architectures with only mass-producible batch fabrication in the front end.” For example, the team is trying to keep the design simple while maintaining an optimal performance level, which presents yet another obstacle.

In a conventional design of a windmill, the hinge is a small portion because the blade takes up most of the space. At the micro-scale, the blade has to be small, which means the hinge needs to be even smaller. When the windmill interacts with wind, there is debris, dust, and moisture in the air. The moisture can create stiction, which is when the water molecules start to become glue, binding the materials together. This may be resolved with some sort of lubricant, but according to Chiao, the lubricant for metal MEMS devices could be completely different from what is being used in larger ones.

**Commercial Potential**

Chiao’s team anticipates a lot of commercial potential for their idea, including a charging platform for energy harvesting to provide power in areas that it is not available. They also believe it could be used to power wireless sensors in monitoring systems for bridges, highways, and buildings.

“Right now the United States is facing an infrastructure problem, and one structure requires a hundred or more sensors to monitor the environmental issues. It’s not a good idea to send someone once a year to replace all the batteries within all the sensors,” says Chiao. “This micro-windmill, energy harvesting platform would make the sensor [5] more power independent by allowing it to continuously operate. This is also an enabler for wireless sensors used for the Internet of Things. Imagine millions of wireless sensors that can be independently placed in remote locations, around cities, and around us to communicate with the cloud so we can quickly assess the environments, disaster scenarios, or infrastructure health by getting a more complete picture from a big data network.”

Since their announcement, Chiao has received a lot of responses for potential applications. Several companies have approached them with ideas, and they have even gained international recognition from Germany, Taiwan, and Korea.

“The idea can also be applied to different industries, such as computers, portable electronics, sensors, and automotive,” says Chiao. “People see the potential and like to know more.”
According to Chiao, his goal is to try and establish a platform that will inspire interest everywhere.

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