Gallium oxide could have low cost in future, reckons NREL technoeconomic analysis

The cost of manufacturing a six-inch Ga_2O_3 wafer in USA is less than a third of that for a silicon carbide wafer, halving the cost of power electronics.

The potential use of gallium oxide as a power electronic technology of the future is borne out by a new technoeconomic analysis by the US National Renewable Energy Laboratory (NREL). The findings reveal that gallium oxide wafers could be three to five times cheaper to manufacture than related silicon carbide technology, according to the paper 'How Much Will Gallium Oxide Power Electronics Cost?' (to be published in the April edition of Joule at https://doi.org/10.1016/j.joule.2019.01.011).

The proportion of electricity that flows through power electronics is forecast to rise from an estimated 30% currently to 80% in the next decade, making it critical to optimize efficiency of power electronics for use in the generation, transmission, storage and use of that energy.

"If you look at the grid of the future, you'll see more power electronics for renewables and electric vehicle charging," says Johney Green, associate lab director for Mechanical and Thermal Engineering Sciences at NREL. "As we get more and more of these power electronics-based devices on the grid, it changes the physics of the grid. We really need to understand how these devices will impact the grid and how to control them." Green, who championed the analysis, is a co-author of the paper along with Samantha Reese, Timothy Remo, and Andriy Zakutayev. The four authors come from three different research directorates at NREL.

The analysis into the cost of gallium oxide dovetails with ongoing research at NREL into the use of wide-bandgap semiconductors for power electronics. Power electronic devices made of silicon, with its narrow bandgap, produce too much heat when confined in a small space. Wide-bandgap semiconductors, such as gallium oxide, silicon carbide (SiC) and gallium nitride (GaN), can potentially operate more efficiently in a tight space, so components utilizing a wide-bandgap semiconductor can be more compact and hence lighter.

Both gallium oxide and silicon carbide are being considered as replacements for silicon in power electronic devices. Silicon carbide is already in use, but wide-

NREL researchers Timothy Remo (left), Samantha Reese, Andriy Zakutayev and Johney Green used technoeconomic analysis to determine 'How Much Will Gallium Oxide Power Electronics Cost?', a paper published in Joule. (Photo by Dennis Schroeder/NREL)

spread adoption has been hampered by its relatively high cost. Gallium oxide semiconductors are not being used commercially, but several companies are working on device prototypes, says Zakutayev, a materials scientist whose work involves the development of new materials for use in renewable energy technologies. While there have been published papers indicating that the low cost of gallium oxide could be a future advantage, the NREL research is the first to provide a quantitative analysis, it is reckoned.

The new analysis could prompt further materials and device research into the use of gallium oxide, which has been relatively overlooked compared with silicon carbide and gallium nitride devices. Reese (a senior analyst/engineer in NREL's Strategic Energy Analysis Center) and Remo, along with other analysts at NREL, published a cost analysis in 2017 for the use of silicon carbide in medium-voltage motor drives. "It's hard to get the funding for the technical research if you don't have a cost motivation, given that silicon carbide's already in the market," says Reese. "But it's hard to get money to do the analysis of the cost if you don't have technical results demonstrating the capabilities."

For the gallium oxide analysis, a bottoms-up cost model created around the manufacturing process considered such factors as crystal growth and ingot machining to approximate the fabrication of crystal wafers ready for use in a device. The assumptions used in the model included an ingot 1m long, a wafer 6 inches in diameter, and a manufacturing volume of 5000 wafers a month.

The NREL analysis determined that it would cost $283 to manufacture a 6-inch gallium oxide wafer in the USA (less than a third of the $919 it would cost to make a silicon carbide wafer). The significantly lower wafer cost enables the gallium oxide-containing power electronics (which also consist of many other components and packaging) to be twice as cheap. The techno-economic modeling relies on manufacturing scenarios that are not currently commercialized, but it's projected to hold true once R&D advances move gallium oxide into mainstream applications.

The potential exists to reduce the cost of gallium oxide wafers even further. More than half of the cost of a gallium oxide wafer comes from the use of iridium as the crucible in which the crystal ingot is grown. Using an alternative material, such as molybdenum or tungsten, could bring the price of gallium oxide semiconductors down further.

Unlike gallium oxide, gallium nitride semiconductors are already in widespread use in applications other than power electronics, because they form the basis of light-emitting diodes and solid-state lighting. "The biggest difference is that gallium oxide crystal wafers should be easier to scale up in size, and decrease in cost, compared to gallium nitride," Zakutayev says.

In addition to the new analysis, NREL is a part of the five-year-old Next Generation Power Electronics National Manufacturing Innovation Institute (PowerAmerica), whose mission is to make wide-bandgap semiconductors cost-competitive with their silicon-based counterparts. ■

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