Study reveals molecular breakdown at the sub-20 nanometer scale

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Engineering researchers at the University of Arkansas and the University of Nebraska-Lincoln have discovered a novel nanomachining process that will help manufacturers produce superior nanoscale devices to perform important functions such as detecting DNA and precisely controlling drug release.

The research, to be published in the *Physical Review Letters*, focuses on the dielectric breakdown of liquid organic molecules introduced during the nanomachining process. Dielectric materials do not conduct electric current. The collaborative research was funded by the National Science Foundation's division of Civil, Mechanical and Manufacturing Innovation.

"Understanding dielectric properties of very thin layers plays a critical role in next-generation electronic devices," said Ajay Malshe, professor of mechanical engineering at the University of Arkansas. "In the past 10 years, the machining process in conductive materials for these devices has been scaled down to the micro level - between 3 and 10 micrometers. With this project, we demonstrated dielectric breakdown for the first time at the nanolevel."

"This understanding is an important step toward achieving reproducibility, reliability and repeatability when machining at sub-20 nanometer scales, which is vital for the realization of nanoscale active systems," said Kamlakar Rajurkar, professor of industrial engineering and management systems at the University of Nebraska-Lincoln.

Using a scanning-probe microscope with additional features, Malshe, Rajurkar and Kumar Virwani, a recent engineering doctoral graduate and co-author of the study, devised an electric-discharge machining and manufacturing platform and discovered the breakdown of dielectric molecules across a gap less than 20 nanometers in length. The nano-electric machining platform allowed the researchers to position a cathode tip - a negatively charged electrode acting as a point - against an anode plane - a positively charged plane - and sandwich the organic molecules between them.

The voltage applied in the gap generated an intense electric field. After making the cut and ceasing voltage, the researchers observed the behavior of the organic molecules, which were confined in the gap. Rajurkar identified the above process as nanoscale electric discharge machining, or nanoEDM.

Organic molecular medium is an integral part of the machining set up, Malshe said. Understanding its dielectric and breakdown properties is critical to determining how the process of machining works and will lead to improving machining performance and speed.

Understanding the molecular behavior and breakdown of dielectric media during the machining of extremely resistant materials is also critical to developing commercial products with features such as nanopores for detecting DNA, nanojets for controlled drug release and nozzles for nanofluidic devices. There is great demand for such features in difficult-to-machine metals such as gold, titanium and platinum, silicon and ceramics such as silicon nitride, silicon dioxide and conductive polymers. The research also expands knowledge of organic and molecular electronics.

"The success of nanoEDM will allow industry to work on a variety of electrically conducting and semi-conducting materials in a non-vacuum environment," Virwani said. "It will be instrumental for a wide range of emerging applications."

Source: University of Arkansas