For Immediate Release

For More PR Information, Contact:
Gaye Jacobs, Power PR
P (310) 787-1940
F (310) 787-1970
E-mail: press@powerpr.com

Electrons, not Ions, Provide Superior Plasma Etching of Nanoscale Semiconductor Devices

Accelerated waves of electrons, not ions, gently lift away atoms for superior etching and atomically smooth surfaces

In semiconductor fabrication, the traditional approach to dry etching has been to utilize RF plasma to bombard the surface of the wafer with positive ions to remove material between masking layers.

Although ion etching has been effective for decades, however, it fails to produce the precise, sharp, nano-sized structures and pathways required in next generation devices. The process also generates significant amounts of heat that can damage underlying material layers, and for compound semiconductor materials such as GaN or SiC it can change the surface atomic ratios.

Now, in a move that goes against the grain of established traditional views of etching, VelvETch together with PVA TePla America have commercialized a new system which uses the approach called Electron Enhanced Material Processing™ (EEMP™) that utilizes the power of electrons – not ions – to much more precisely remove material at the nano-level.

In EEMP, precisely controlled waves of electrons are accelerated to the surface of the material at specific voltages designed to create chemical reactions that release the surface atomic bonds, allowing the material at the surface of the sample to be gently lifted away. The full-scale immersion by electrons allows the item being processed, such as a wafer, to be completed at an etch rate comparable to RF plasma etching.

EEMP is flexible, allowing various factors to be precisely controlled to etch essentially any material, including thin nano-layers and quantum well structures. EEMP can also be fine-tuned and controlled to achieve atomically smooth surfaces to enable the fabrication of quantum computing devices.

EEMP has unique applications for the current generation of high bandgap compound semiconductors made of gallium nitride, gallium arsenide and silicon carbide.

Electron Etching

According to Samir Anz, he has been hearing “Electrons don't etch” for decades, “but this is far from the case.”

“This is <u>not</u> an electron-beam scanning technology,” says Anz, co-founder of VelvETch, the company that developed the EEMP technology. “We emphasize this because when people hear ‘electrons’, they think ‘electron beam.’ This is a full-scale immersion technology. The entire semiconductor wafer or substrate is processed at all points, at the same time.”

Given their relatively low mass compared to the ions used in commercial etching, electrons are often not considered a viable option to etch by bombardment.

“No one believed electrons could possibly etch materials at the normal rates of ions, because an electron is about 2,000 times lighter than even a proton. The belief was that if you accelerated electrons there would not be enough momentum to initiate a reaction,” says Anz.

However, with EEMP it is not the impact that drives the etching, rather it is a chemical reaction induced by a loss of electrons from the bonds at the surface that causes surface atoms to be gently released, explains William A. Goddard III, an expert in theory of chemical and materials reactions and Professor of Chemistry, Materials Science, and Applied Physics at Caltech.

“We developed a way to study this process using quantum mechanics, and discovered that electrons in the discharge with the proper energy can remove an electron buried deep inside the atom, which in turn is filled with an electron from a bond while simultaneously knocking a second electron out of a bond,” explains Goddard. “When you lose two electrons from a bond, it breaks.” This is called an Auger event (pronounced like Ojai). “Since Auger processes occur only at the surface, EEMP leads to extremely smooth surfaces.”

Now commercialized by VelvETch after decades of research and development, EEMP is conducted in a jointly designed advanced plasma system platform provided by PVA TePla America, utilizing a proprietary bias waveform signal that pulls the electrons down to the surface being processed.

“The bias waveform is applied across the entire surface of the sample and that is the mechanism that accelerates a wave of electrons towards the whole surface of the sample,” explains Anz.

Because electrons have little mass, there is no impact damage to the surface and only nominal heat is generated as a result of the chemical reaction, thus the sample remains at room temperature.

The process is extremely flexible allowing EEMP to be used in a variety of applications and materials. The variables that can be manipulated and tuned to achieve specific unique results include the gases utilized in the chamber, the electron energy in the discharge (based on the material to be etched), and the temperature.

Plasma Etching

EEMP stands in stark contrast to the traditional approach to dry etching techniques used in the semiconductor industry, such as reactive-ion etching using RF plasma.

In the traditional approach, plasma is created by applying a radio frequency signal (typically 13.56 Megahertz) that causes the atoms or molecules of the gases introduced into the chamber to increase in temperature until they ionize into a plasma. A separately controlled radio frequency signal under the wafer pulls the positive ions down in a virtual "atomic sandblasting" of the surface of the material.

Due to the mostly vertical delivery of reactive ions, RF plasma etching can produce anisotropic etching useful to fabricate relatively sharp corners, flat surfaces and deep cavities.

However, "When ions with over 1000 volts of energy hit the surface," explains Professor Goddard "You get a couple of nanometers of damage automatically, even in the best case." This creates significant problems as transistors are miniaturized to 10 nanometers and less. Moreover, ions that impact the surface with enough force to etch can be embedded several layers deep, causing electronic damage along with backscatter.

In addition, ion etching produces small undercuts underneath the masking layer to form cavities with sloping sidewalls. Even a half nanometer undercut on each side can account for 10% of the width of a 10-nanometer transistor leading to incorrect function.

Slight damage from reactive-ion etching was not a critical concern with silicon, but ion bombardment damage can cause serious problems with compound semiconductors such as silicon carbide, gallium nitride, and gallium arsenide because the ions affect the various elements differently, leading to incorrect atomic ratios at the surface.

Compound Semiconductor Materials

Compound semiconductor materials are comprised of more than one element. Current high bandgap compound semiconductors include gallium nitride, gallium arsenide and silicon carbide.

Gallium nitride is very important for transistors to operate at higher frequencies, voltages, and temperatures, including the microwave power amplifiers used for 5G wireless base stations, satellite communication, and military radar systems.

Gallium arsenide allows for faster operation, wider band gap, and operation at higher temperatures, and silicon carbide is used in semiconductor electronics devices that operate both at high temperatures and high voltages.

Reactive-ion etching removes different elements at different rates, modifying the surface stoichiometry, or ratio, of compound semiconductor elements.

“With gallium nitride, ion etching tends to remove nitrogen faster than gallium, leading to a gallium-rich surface with poor electrical properties,” explains Stewart Sando, a co-founder of VelvETch. Consequently, to eliminate excess gallium, wafers are often dipped in wet chemistry to restore the proper ratio of elements at the surface, hardly appropriate for new generation nanoscale devices.

EEMP preserves the stoichiometry of compound semiconductors by carefully controlling the energy of the electrons in the discharge.

This advantage of EEMP also applies to quantum well structures, which sandwich a thin layer of one semiconductor between two layers of another semiconductor material with a wider band gap. Examples include aluminum gallium arsenide that confines the electrons to a gallium arsenide region, as well as indium gallium arsenide and gallium arsenide.

Quantum wells are in wide use in laser diodes, light emitting diodes (LED), high electron mobility transistors, infrared photodetectors and infrared imaging arrays.

“By controlling the electron energy, we can target the etching of a specific material, stopping automatically when we hit another material, without creating any damage to the underlying material,” explains Sando.

Additional Benefits

Among the additional benefits of EEMP is the ability to achieve atomically smooth surfaces due to the nature of the process, which removes atoms layer-by-layer, beginning with any existing peaks.

“If there is any roughness on the surface, even at an atomic level, EEMP will smooth it down to within one lattice constant of atomic smoothness, which is less than 0.25 nanometers in silicon,” says Sando.

In quantum computing, atomically smooth surfaces are required for optimal performance. EEMP can also be used to smooth a surface prior to growing another material on top of it using molecular beam epitaxy or chemical vapor deposition.

“When gallium nitride is grown on silicon carbide for high frequency, high power applications, the silicon carbide must be perfect. Otherwise its defects will propagate into the gallium nitride lattice degrading electrical performance,” says Sando.

The fact that EEMP generates almost no heat is another major benefit. RF-based ion etching generates high temperatures that can cause physical and electrical damage to compound semiconductors and integrated circuits. The temperatures are so high that cooling must be integrated into most plasma etching equipment.

Excessive heat can damage the very thin, 10-20 nanometer layers of quantum well stacks and even modify the electrical properties and structural integrity of modern low-K dielectric materials.

“The hotter the material gets, the more undesired reactions occur,” explains VelvETch’s Anz. So, we want to suppress thermal chemistry pathways and parasitic processes by keeping the temperature low.”

With EEMP the chemical reaction produces only a minimal amount of heat. Anz believes this contributes to the broad dynamic range of the process. “This enables us to use temperature as an additional control, as opposed to something that must be mitigated,” explains Anz.

Commercializing the Process

Today, Anz says plasma chambers are available for EEMP along with contract processing services through a partnership with industry leader PVA TePla, a company that designs and manufactures plasma systems.

In addition to re-writing the book on etching, VelvETch and PVA TePla decided to utilize an “old-school” approach in designing the direct current (DC) based plasma system – rather than RF – to generate the low temperature plasma required.

“With a DC plasma, we can generate a controlled positive column that is extremely rich in low energy electrons,” explains Anz. “Our DC reactor design will provide a high-level of reliability and up-time for our customers.”

PVA TePla America located in Corona, California is a global supplier of custom plasma equipment used in the Semiconductor, Electronics and Medical Device markets for surface modification of a wide variety of components and materials. They also provide in-house Research & Development, and Contract Services for their customers.

For more information, contact VelvETch at sfsando@velvetch.com. For PVA TePla America, call (951) 371-2500 or (800) 527-5667, billm@pvateplaamerica.com or visit www.pvateplaamerica.com.

###