PPPL digest
PRINCETON PLASMA PHYSICS LABORATORY
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PPPL Researchers Study Plasma Sterilization

Hundreds of billions of plastic food and beverage containers are manufactured each year in the U.S. All of these packages must undergo sterilization, which at present is done using high temperatures or chemicals. Both of these methods have drawbacks. Chemicals often leave a residue that can affect the safety and taste of the product, and produce undesirable waste. Heat is effective and sufficiently rapid, but necessitates the use of costly heat-resistant plastics that can withstand sterilization temperatures. What if a new method could be found that eliminated the need for chemicals or heat-resistant plastics?

Plasma just might be the answer. At PPPL, a team is conducting a small-scale research project studying plasma sterilization. This method, if successful, could be used to sterilize food and beverage containers, leading to an enormous savings — potentially hundreds of millions of dollars annually for a large soft drink manufacturer.

New Plasma Approach

"We have experiments indicating it is possible to kill microbes using a new plasma approach," noted John Schmidt, lead scientist of PPPL's Plasma Sterilization project. Schmidt cautioned, however, that the research is preliminary. "These experiments need to be published, peer reviewed, and repeated by other researchers to assure reliability. Physics research will be followed by considerable development work to arrive at a practical system for assembly line use," said Schmidt, who has been awarded a patent for a plasma sterilization system (see sketch on page 2). Working with Schmidt are PPPL Technology Transfer Head Lewis Meixler, physicist Doug Darrow, engineer Nevell Greenough, and technicians Gary D'Amico and Jim Taylor.

John Schmidt, lead scientist for the Plasma Sterilization project, next to the experiment.

The PPPL Experiment

To get started, PPPL researchers modified old equipment that had once been used to study radio-frequency (RF) waves for fusion applications. It consisted of a vacuum chamber equipped with an RF source. A brass sphere measuring one inch in diameter was mounted at the center of the chamber.

Above at the plasma sterilization experiment are, from left, Gary D'Amico, Nevell Greenough (kneeling and looking into sterilization apparatus) and Lewis Meixler. The experiment is on the first floor of the L-wing.

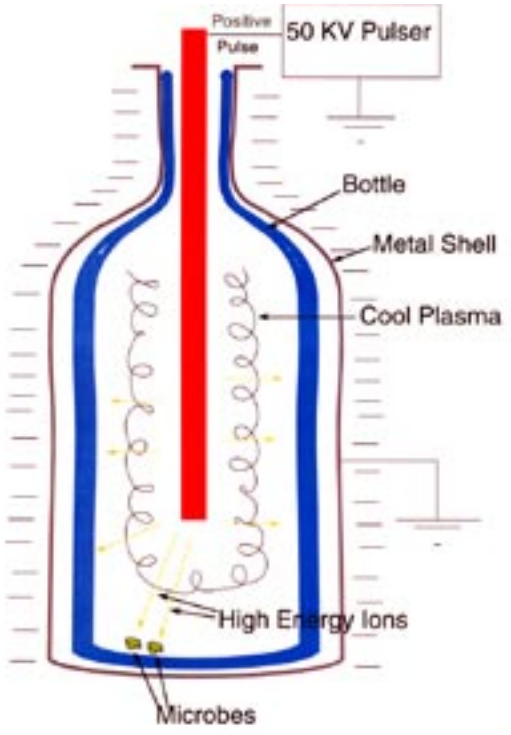
In preparation for experiments, the sphere is removed and sent to a commercial biological testing laboratory in Hightstown where a known number of spores of bacillus subtilis, a non-toxic microbe commonly used as a standard in lab testing, are placed on its surface. Following an experiment, the sphere is returned to Hightstown where technicians determine the number of spores killed in the process.

Fusion experiments at PPPL have generated plasmas with temperatures in the hundreds of millions of degrees centigrade. For killing spores, the PPPL researchers start with "low-temperature" hydrogen plasmas in the range of 50,000 degrees centigrade. At that temperature, the hydrogen ions are moving much too slowly to kill spores quickly. Rapidly pulsing a 50-kilovolt potential between the sphere and the vacuum chamber solves the problem. The sphere is charged negatively and the vessel is at ground. Under these circumstances, the positively-charged hydrogen ions accelerate toward the sphere in pulses energetic enough for the ions to pierce the hard outer shell and soft inner core of the spore. Recent experiments employed 4,000 10-microsecond pulses, which reduced the population of live spores by a factor of 100-1000 — the kill ratio.

In the Real World

In the real world, equipment and processes suitable for the assembly line of a packaging plant would be needed. In such a situation, sterilization time is precious. RF generates a low-temperature hydrogen plasma inside the evacuated container, which is held in place by a surrounding conducting shell. An electrode is inserted into the container (see sketch below). The plasma is then subjected to a pulsed differential of 50 kilovolts, with the electrode pulsed positively and the conducting shell grounded. This causes energetic pulses of hydrogen ions to accelerate away from the electrode toward the conducting shell. On the way, they collide with spores present on the inner surface of the container. The hydrogen ions are energetic enough to penetrate the durable proteinaceous outer cover of the spores.

"These high-energy hydrogen ions stop very quickly and consequently deposit all their energy over a very small distance, a few microns, which, as it turns out, is the size of the spores. So relatively modest currents of energetic hydrogen ions can do a large amount of damage inside the spores by messing up their DNA," said Schmidt. He estimates that a sufficient kill ratio could be attained by 10-microsecond pulses every millisecond for a few seconds. Further experimentation is needed to confirm the number of

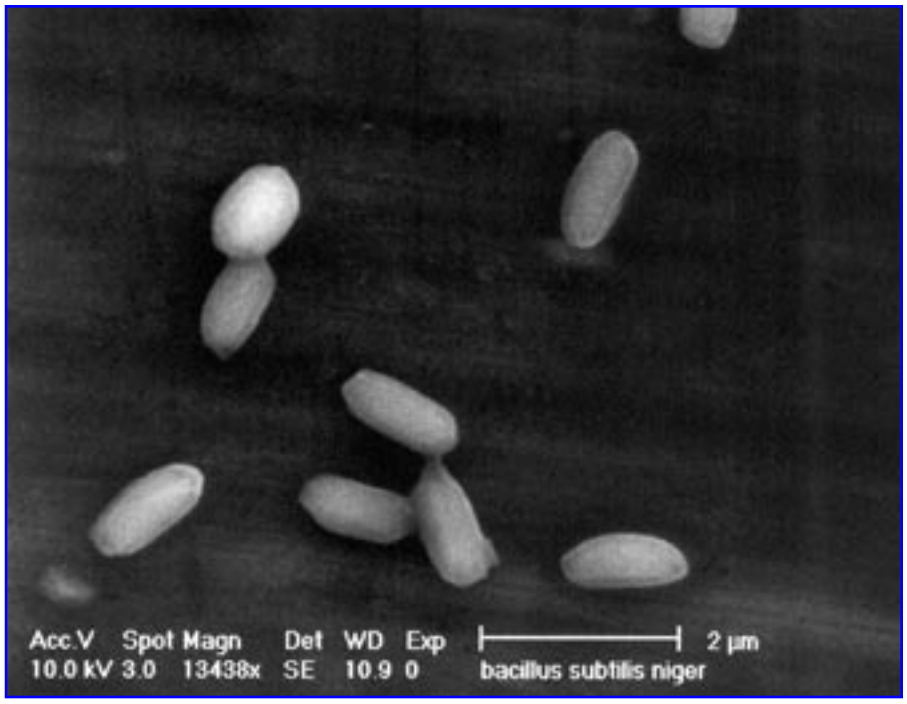


A sketch of the plasma sterilization apparatus.

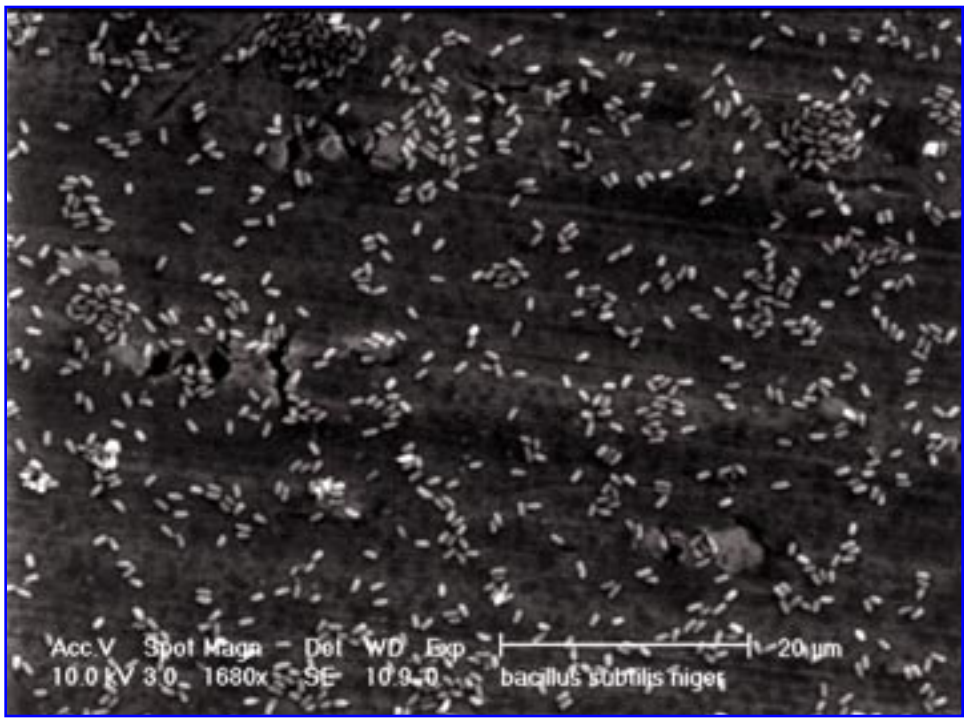
10-microsecond pulses necessary to reach the required kill ratio. A few seconds' processing time per container would make the system feasible for the assembly line.

The effectiveness of the hydrogen ions can be compared with that of gamma rays or X-rays used to sterilize bulk materials. Gamma and X-rays have long penetration depths, so they don't do as much damage per unit length as the hydrogen ions. "Textbooks contain the radiation damage coefficients that are required to kill the relevant microbes. I am confident that we will be able to attain these," said Schmidt.

A small business has been started to do the development work leading to a potential commercial application.



Shown is a scanning electron microscope image of a small group of bacillus subtilis var Niger spores magnified approximately 13,500 times. The image shows that the spores are approximately 1 µM long and approximately 0.5 µm in diameter.



Shown is an example of the spores used in the plasma sterilization experiment. The image, made by a scanning electron microscope, is of bacillus subtilis var Niger spores magnified approximately 1,700 times. It illustrates the typical spore density on the surface of the brass sphere that is inserted into the sterilization apparatus, and shows that the spores are fairly evenly distributed over the surface to be sterilized.

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