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# Inducing a Dielectric Barrier Discharge Plasma Within a Package

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# Inducing a Dielectric Barrier Discharge Plasma Within a Package

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*Abstract***— Cold atmospheric plasma offers significant potential as a nonthermal decontamination tool for food and medical applications. We present results of a dielectric barrier discharge (DBD) plasma induced in a gas confined by a polymer package. The resultant discharge and contained afterglow are found to have a strong antimicrobial effect.**

*Index Terms***— Atmospheric-pressure plasmas, glow discharges, nonthermal plasma, plasma diagnostics.**

DIELECTRIC barrier discharge (DBD) plasma is generally induced within small gaps of the millimeter range in inert gases (He, Ar). The present work develops a DBD setup that can achieve microbial reductions in sealed packages of much larger gap sizes. Fig. 1(top) is a photograph of cherry tomatoes being treated with helium gas plasma, generated inside a 3.5 L sealed commercial polypropylene package. The discharge is confined to the diameter of the electrodes. The image was taken using an Olympus E620 single lens reflex camera with 40-mm lens at 200 ISO. The image was integrated over 30 s duration to effectively capture the discharge. The strong antibacterial effects of the plasma setup are clear from the scanning electron micrographs in Fig. 1(bottom). The cell surface of *Listeria spp* are dramatically altered leading to cell inactivation. Fig. 2 shows the emission spectra of the discharge. A 20-mm diameter lens was used to collect the light from a column across the diameter of the package and focused onto a 200 $\mu$m multimode fiber connected to Stellarnet EPP 2000C-25 spectrometer (integration time of 5000 ms, averaged over 10 spectra, 1.5-nm resolution, radius of curvature of diffraction grating of the spectrometer = 40 mm, 590 grooves/mm, entrance slit width of 25 $\mu$m).

The dominant color in the image is violet–blue due to the spectral emissions from helium and traces of nitrogen. From the emission spectrum it is evident that there are almost no continuum emissions between 200 and 850 nm. The low continuum emission indicates that gas temperature is not high, i.e., it is not different significantly from the ambient temperature. This is desirable considering that a higher plasma temperature will have detrimental effect on the food packaging polymer and/or the food itself [2]. Nitrogen dominates the spectral emission (Fig. 1). In the 300–450 nm spectral range, the strongest emission is the $N_2$ second positive system ($C^3\Pi_u^+ \rightarrow B^3\Pi_g^+$), the $N_2^+$ first negative system ($B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$) and the OH ($A^2\Sigma^+ \rightarrow X^2\Pi$) band that shows a red degradation with the main band head at 308.9 nm.

The $N_2$ molecular bands at $\lambda = 337$ nm ($\upsilon = 0 \rightarrow \upsilon' = 0$) is the most significant one (for a plasma diagnostic) for the whole $N_2$ second positive system. The upper $N_2(C^3\Pi_u^+)$ energy level can be populated in several ways. First, it can be populated through the direct electron impact excitation from the $N_2$ ground state. A second possible population mechanism of the $N_2(C^3\Pi_u^+)$ state is through the electron recombination of $N_2^+(X^2\Sigma_g^+)$ followed by decay. The $N_2^+(X^2\Sigma_g^+)$ is populated through the Penning reaction and/or the charge transfer from $He_2^+$ ions. The temporal profile of the 390–450 nm line therefore reflects the evolution of the helium metastables and molecular ions. The presence of a strong $N_2^+$ emission in the spectrum indicates a significant role of helium metastable atoms. Therefore, monitoring the helium metastable density is an important plasma parameter. The lower energy level of He I 388 nm spectral emissions is a metastable helium triplet state, and the He388 spectral line emission can be used for the monitoring of a metastable helium atom in the triplet state. The similar case is with emission from a helium singlet state, i.e., the He I 501 nm emission represents helium metastable atoms in singlet helium states. Molecular nitrogen, because of collisions with helium metasables, has very rich UV emissions (Fig. 1). Although an increasing intensity of

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Fig. 1. Top: DBD plasma treatment of tomatoes in-package, a high-voltage electrode (60 kV RMS). Bottom: Scanning electron micrographs of untreated and plasma treated *L. monocytogenes* NCTC 11994.

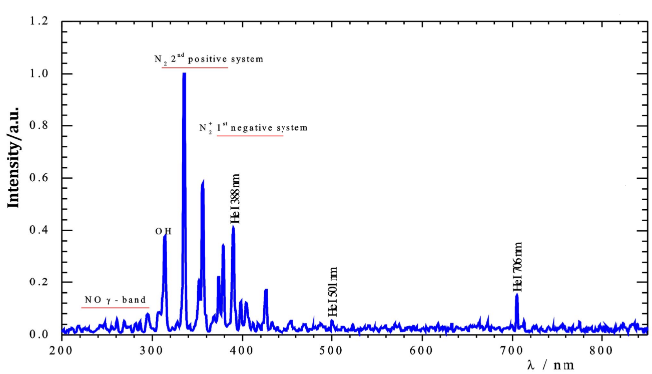


Fig. 2. Emission spectrum of the discharge.

UV light is useful for microbial inactivation its efficacy is limited for shadowed areas or porous material. Consequently, the approach relies on active species for a useful effect.

In the vast majority of atmospheric plasma discharges, apart from molecular nitrogen spectral emission, NO (when $N_2$ is exposed to oxygen), and OH (formed by the plasma discharge in a humid ambient air) are present.

This in-package plasma approach has been successfully employed for numerous gases including air and modified atmospheric packaging gases commonly used in food applications. A key advantage of in-package cold plasma approach is that the bactericidal molecules are generated and contained in the package, allowing extended exposure to the target microorganism, while reverting back to the original gas within few hours of storage.

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