Atmospheric pressure cold plasma processing of bioactive packaging applied directly to fresh fruits and vegetables

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Résumé

Described here is research for which the long-term goals are to improve public dietary choices and improve the economic return to fruit and vegetable producers through the development of processing techniques for healthier and safer fresh fruits and vegetables. Bioactive thin-film packaging can use a wide variety of immobilized molecules, antimicrobials, proteins, vitamins, yeasts and bacteria to improve many features of fresh fruits and vegetables. These bioactive species can become denatured (along with the fruits and vegetables being processed) at processing temperatures greater than 40ºC. Needed is a bioactive film deposition technique that is not dependent on thermal energy or harsh solvents. The central hypothesis in this research is that atmospheric pressure cold-plasma processing will provide a practical, non-thermal, non-toxic and non-allergenic means to apply bioactive thin films to fresh fruits and vegetables.

Introduction

Bioactive thin-film packaging applied directly to produce is a novel technology. Food safety and food quality for fresh fruits and vegetables will be improved by 1) extended shelf life; 2) improved nutrient content; 3) improved sensory qualities for the consumer; 4) introduction of antimicrobials; 5) improved gut health via probiotics and 6) extension of produce shelf life. Conventional thin film processes require heat or harsh solvents to form and attach the thin film thus they cannot apply active packaging films directly to fruits and vegetables without degrading the produce and/or degrading the functionality of the bioactive species that is to be immobilized in the matrix film. This two-page abstract describes research currently being conducted on this topic at Washington State University in Pullman, Washington. An early publication related to active packaging was a book edited 1.5 decades ago [1]. More recently flavonoids and phenolic acids have been identified as antimicrobial substances [2, 3] that have applications in active packing material that allows fresh fruits and vegetables to resist spoilage [4]. Cold plasma techniques have been used to treat the surfaces of nuts [5] and form plasma-polymerized films for controlled release of bioactive compounds [6]. It is reported in the literature that development of active packaging is hampered substantially by the thermolability of the active compounds which must be thermostable when entrapped in plastic films [7]. For example, ascorbic acid has been observed to take on a brown color in processes that used a temperature greater than 80°C [8].

Experimental setup

The existing experimental setup includes important modifications to hardware described recently in the literature [9]. In the work described here a streamer region is established between an array of 12 high voltage stainless steel needles and a grounded stainless steel torus. The reactor is shown in Figure 1. The carrier gas is argon with flow rate on the order of 100 standard cubic centimeters per minute (sccm) with surrogate precursor monomer molecules consisting of acetylene (flow rate on the order of 10 sccm.) The acetylene-based radicals flow downstream from the high voltage streamer region and form a thin film of plasma-polymerized acetylene on the substrate. Substrates include glass, highly ordered pyrolytic graphite (HOPG), mica and eventually fresh fruits and vegetables. Bioactive species will include probiotics, vitamins and antibacterial agents but the surrogate bioactive species used in the present work will be the antimicrobial molecule benzoic acid. Standard bioactive assessment techniques will be used to evaluate bioactive species functionality before and after processing [10, 11]. Thin film science diagnostic techniques that will be used to evaluate the bioactive films include the environmental scanning electron microscope (ESEM); atomic force microscopy (AFM); Fourier transform infrared spectroscopy (FTIR); x-ray photoelectron spectroscopy (XPS); the direct pull-off (DPO) method will measure film adhesion; BET isotherms will be used to measure specific surface area (porosity); a

thermo gravimetric analyzer (TGA) will measure thermal properties of the film; a contact angle meter will measure surface energy of the film; x-ray diffraction (XRD) will measure the crystalline structure within the film; and electrical permittivity of the film will be measured with impedance spectroscopy. Electrical energy input will be quantified by measuring with Rogowski coils corona current pulses. This energy input results in atomic processes such as ionization, bond scission, and excitation of atomic and molecular species to excited electronic states. Measuring this energy gives the team a technique with which to adjust the electrical energy input per unit of monomer mass. The bioactive species will be injected into the radical feed stream by a nebulizer. The bioactive species will be incident on the substrate along with radicals that are formed as the precursor molecules experience bond scission in the streamer tubes located in the cold plasma portion of the reactor. The bioactive species are immobilized in the growing matrix film via entrapment in pores or via covalent bonding to the matrix material.

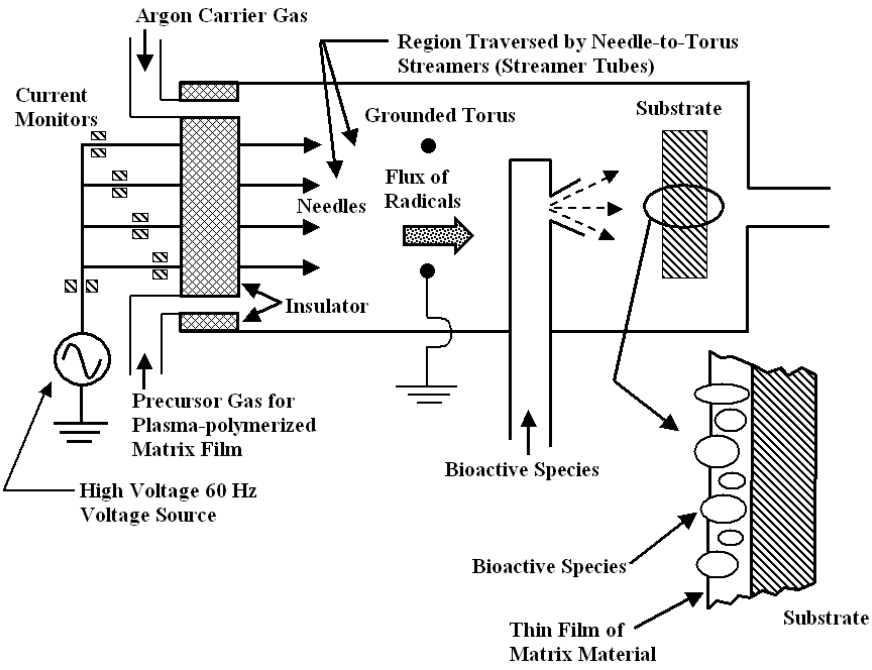

Fig. 1: This schematic diagram shows an artist's rendition of the atmospheric pressure cold plasma reactor used in this research. In the actual reactor design the carrier gas and precursor gas are mixed thoroughly before approaching the needle array. Not to scale.

Discussion and future work

An optimally designed reactor is one that generates appropriate radical species in the streamer tube regions and then facilitates transport of these radicals (without quenching of their dangling bonds) to the substrate with sufficiently high flux. Consumers, retailers, and producers will benefit from this technology as minimally processed fruits and vegetables become more nutritious, become more appetizing, contain fewer food-borne pathogens, and exhibit a longer shelf life. The effluent stream from this process can be nearly eliminated if the argon carrier gas is recycled. Nutritionally designed food systems that will make immediate use of this technology will promote consumer health via bioactive species that include probiotics [12], antioxidants [8], vitamins [8], and antimicrobials [13].

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