LOW-TEMPERATURE POLYMER DEPOSITION IN AMBIENT ENVIRONMENT CONDITIONS USING DIELECTRIC BARRIER DISCHARGE (DBD) JET WITH APPLICATIONS IN MEDICAL WOUND TREATMENT & STERILIZATION

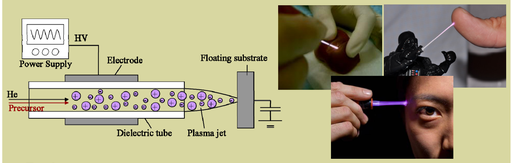
Tsung-Chan "Cliff" Tsai, Jae-Min Cho, Young-Ki Jo, and David Staack

Plasma Engineering & Diagnostics Lab

Abstract

A low-temperature ambient polymer deposition technique has been developed using a floating-electrode dielectric barrier discharge (DBD) jet, which has been known to have the sterilization ability. The purpose of this work is to study the sterilization films deposited by the DBD jet. This work generally can be divided into three categories: (1) analysis of deposited films, including deposition rates, surface morphologies, atomic compositions, and chemical bond concentrations; (2) characterization of the physics behind the used DBD jet in the different operation modes with various parameters; (3) applications of the ambient polymer deposition technique in medicine, such as sterilization, bone fixing, wound sealing, and tissue repairing.

Floating-electrode DBD Jet



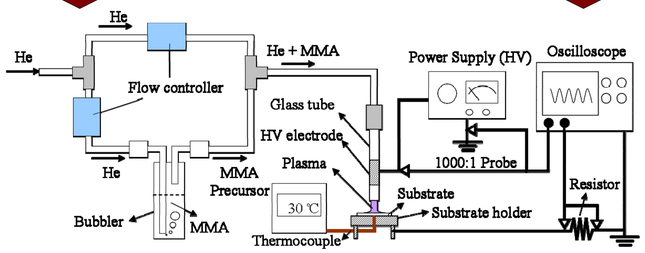
Features:
(1) Atmospheric pressure (2) Low temperature
(3) Stability (Arc-free) (4) High flexibility (Any objects can be treated)

Use DBD Jet to…

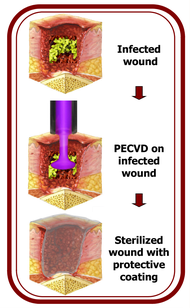
Step 0: Sterilization (current state of the art in literature)
Step 1: Polymer Deposition in Ambient Conditions
Step 2: Sterilization & Polymer Film Deposition on wound model surfaces (agar)
Step 3: Sterilization & Polymer Deposition on wounds/teeth etc…
Step 4: PECVD on people ⬅ Final Destination!!

Sterilization ability in a typical DBD jet

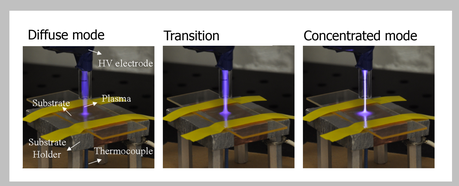
Deposition system setup

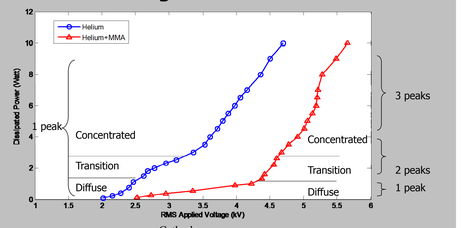


So we can achieve

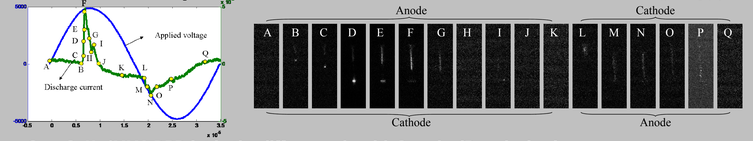


Characterization of the DBD jet

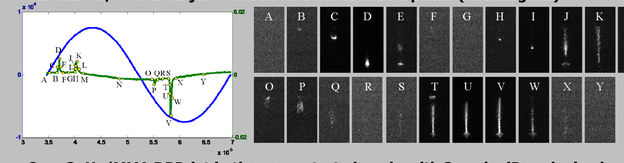




Case 1: Pure He DBD jet in the concentrated mode



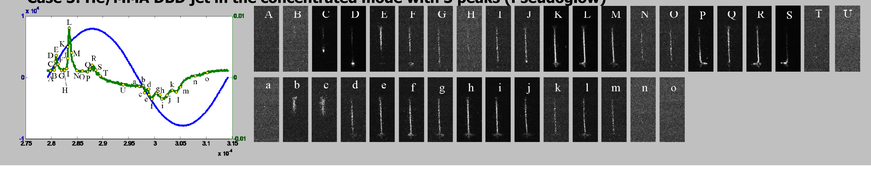
Case 2: He/MMA DBD jet in the diffuse mode with 2 peaks (Pseudoglow)



High speed imaging

Series of two ionization waves (plasma bullets) are observed!!

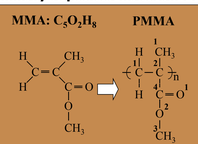
Case 3: He/MMA DBD jet in the concentrated mode with 3 peaks (Pseudoglow)



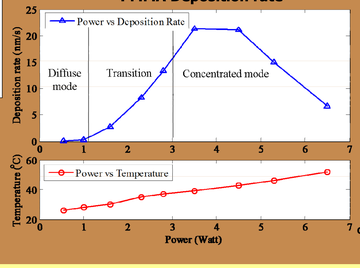
Analysis of deposited PMMA films

Experimental parameters:
(1) Nozzle-to-substrate distance: 10 mm
(2) Helium flow rate: 2.9 slm
(3) Helium flow rate to bubbler: 0.1 slm
(4) Frequency: 28.5 kHz
(5) Preliminary deposited material: PMMA

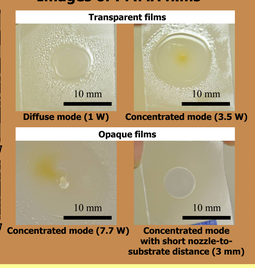
MMA: $C_5O_2H_8$ PMMA



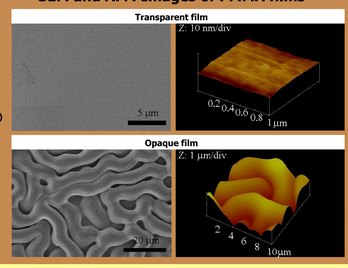
PMMA Deposition rate



Images of PMMA films



SEM and AFM Images of PMMA films

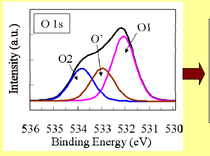


RMS roughness

0.444 nm (High quality)

355 nm (Due to buckling effect)

XPS analysis results

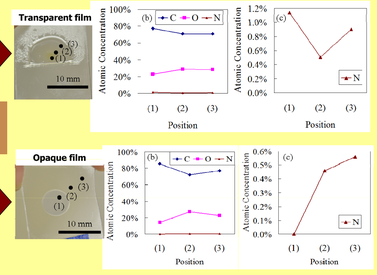


Compared to typical PMMA, additional bonds (C-O-C and C=O) are observed in our deposited PMMA films!!

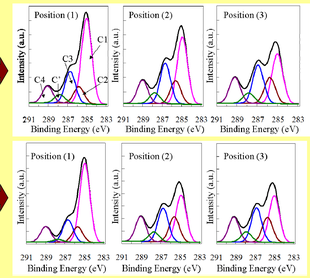
Spectrum	Peak	Binding Energy (eV)	Bond Candidates
O 1s	O1	532.1±0.1	O=C or O−C−O
	O'	532.8±0.2	C−O−C or H−O−C
	O2	533.7±0.2	O=C−O−C
C 1s	C1	285.0	−CH_x
	C2	285.7±0.1	C−COOR
	C3	286.6±0.2	C−O
	C'	287.7±0.2	C−O or O−C−O
	C5	288.9±0.2	O=C−O

Case 1: Different positions

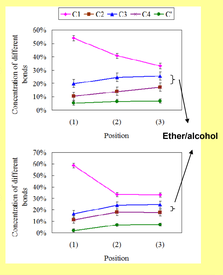
Atomic compositions (C:O ratio and N composition)



Deconvolution of C 1s peak

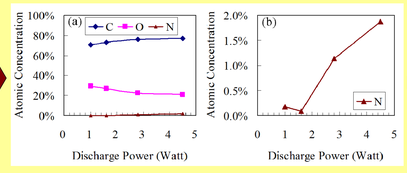


Concentrations of different bonds

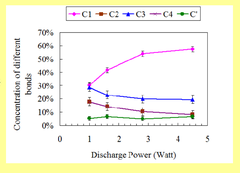


Case 2: Different powers

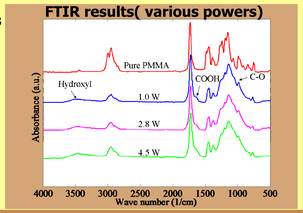
Atomic compositions (C:O ratio and N composition)



Concentrations of different bonds



FTIR results(various powers)



Summarized results:

(a) High deposition rate (22 nm/s) can be achieved with discharge power of 3.5 W at merely 39 °C deposition temperature
(b) Opaque films with wrinkled microstructures can be obtained by using the concentrated-mode DBD jet with relatively high-power operation.
(c) Similar functional groups are observed among the pure PMMA and the films deposited at different powers by using FTIR.
(d) Higher power operation leads to higher C:O ratio in the films, the less retention of ester groups and the higher concentration of the $-CH_x$ groups.
(e) The existence of ether/alcohol groups in the deposited films are also proven by both XPS and FTIR results.

Sterilization & Protective Polymer Films

The idea

1. Pure He (3 slpm) with plasma

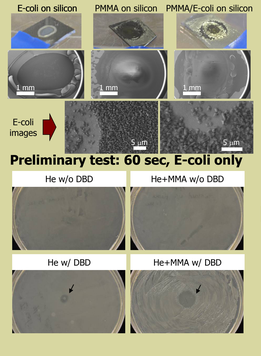
(a) Prepare Agar
(b) Plate bacteria
(c) Treat by DBD jet
(d) Bacteria growth Bacteria colony
(e) Drop bacteria on the treated area
(f) Bacteria growth on the treated area

2. He (2.9 slpm) + MMA (0.1 slpm) with plasma

(a) Prepare Agar
(b) Plate bacteria
(c) Treat by DBD jet
(d) Polymer Forming Polymer film
(e) Bacteria growth Bacteria colony
(f) Drop bacteria on the treated area
(g) No bacteria growth on the treated area

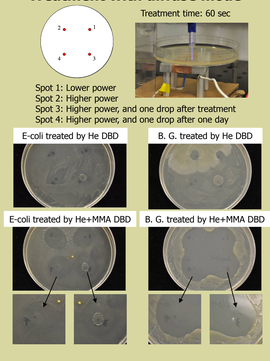
Agar / Bacteria / Plasma

Images of E-coli and PMMA films



Preliminary test: 60 sec, E-coli only

Treatment with diffuse mode



Treatment with concentrated mode