Working in partnership with our customers, we develop innovative applications for tomorrow's products.

COMPANY > PLASMATREAT


Our core business:
Atmospheric plasma treatment

The development of high-efficiency process solutions for surface pretreatment of all types of materials – individually tailored to the requirements of our customers – is the core of our business. Thanks to Openair® plasma technology’s extraordinarily versatile range of applications, we are opening up new industrial application areas almost every day.

Our vision:
Sustainable innovations
Surface Treatment using Plasma Treatment and Corona Treatment

Surface treatment of materials with low surface energy is necessary prior to gluing, printing, painting and coating. Plasma and Corona Treatment Technologies improve adhesion and wettability with a modification of the surface structure using high voltage discharge. High voltage is also applied in Leak Detection for improved quality control.

Surface treatment is necessary due to low surface energy

Increased use of plastic materials such as polyolefines, PE, PP, PS, PC, PTFE and EPDM in the manufacturing industry promotes the need for surface treatment. Plastic materials are easily extruded, blow- and injection moulded, which makes it profitable for manufacturers to use these synthetic materials. The disadvantage using plastic is poor adhesion and wettability caused by low surface energy, which makes it difficult to bond and decorate.

Plasma and Corona Surface Treatment modifies surface structure

Plasma and Corona Surface Treatment changes the surface characteristics by
Atmospheric Plasma | PlasmaTEC-X | Highly improved features

http://www.tantec.com/atmospheric-plasma-improved-features.html
Canady Hybrid Plasma™ Scalpel

Utilizing "Canady Hybrid Plasma™ Technology" A Breakthrough in Electrosurgery

The Canady Hybrid Plasma™ Scalpel is more precise than conventional electrosurgical devices¹
Epitome® and OptiMicro™

The Epitome® Scalpel and OptiMicro™ Needle Electrodes are precision electrosurgical electrodes that can dramatically improve surgical results compared to standard electrosurgical electrodes.

- Product Description
- Epitome® Models, OptiMicro™ Models
- Electrosurgery Brochure (pdf)
- Precision Dissection Electrodes Brochure (pdf)
- Plastic Surgery Brochure (pdf)
- Head and Neck Surgery Brochure (pdf)

Description

Utah Medical Products' specialty dissection electrodes, Epitome® and OptiMicro™, provide excellent healing characteristics.

- Thermal tissue injury is minimized, allowing excellent healing results.
- Focused Peripheral Plasma Blade technology provides an effortless, smooth cut and precise incisional control.
- Cut quickly and smoothly without countertraction.
- Exceptional performance at lower power setting.
- Fits directly into existing electrosurgical systems, dramatically improving their performance.
- Provided sterile for immediate use.
Preface to Special Topic: Plasmas for Medical Applications

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Intense research effort over last few decades in low-temperature (or cold) atmospheric plasma application in bioengineering led to the foundation of a new scientific field, plasma medicine. Cold atmospheric plasmas (CAP) produce various chemically reactive species including reactive oxygen species (ROS) and reactive nitrogen species (RNS). It has been found that these reactive species play an important role in the interaction of CAP with prokaryotic and eukaryotic cells triggering various signaling pathways in cells. © 2015 AIP Publishing LLC.
[http://dx.doi.org/10.1063/1.4933406]
Preface to Special Topic: Plasmas for Medical Applications

Michael Keidar\textsuperscript{1, a)} and Eric Robert\textsuperscript{2}
\textsuperscript{1}Mechanical and Aerospace Engineering, Department of Neurological Surgery, The George Washington University, Washington, DC 20052, USA
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Intense research effort over last few decades in low-temperature (or cold) atmospheric plasma application in bioengineering led to the foundation of a new scientific field, plasma medicine. Cold atmospheric plasmas (CAP) produce various chemically reactive species including reactive oxygen species (ROS) and reactive nitrogen species (RNS). It has been found that these reactive species play an important role in the interaction of CAP with prokaryotic and eukaryotic cells triggering various signaling pathways in cells. © 2015 AIP Publishing LLC. [http://dx.doi.org/10.1063/1.4933406]
The Atmospheric-Pressure Plasma Jet: A Review and Comparison to Other Plasma Sources

Andreas Schütze, James Y. Jeong, Steven E. Babayan, Jaeyoung Park, Gary S. Selwyn, and Robert F. Hicks

(Invited Paper)

Dr. Gary S. Selwyn, Ph.D founded APJeT, Inc., in 2002 and serves as its Chief Technology Officer. Dr. Selwyn is the principal founder of APJeT, Inc. and was successful in obtaining APJeT’s exclusive license for the patent portfolio from LANL and the necessary investment capital from corporate sponsors. He served as Chairman of the Board at APJeT, Inc., and serves as its Director. When he is not inventing, Dr. Selwyn enjoys scuba diving, skiing, sailing, fishing, fitness activities, hiking, camping, museums, classical music, and opera. Dr. Selwyn has been a pioneer in the field of plasma chemistry and plasma processing of materials for 25 years. He is widely known for his discovery of plasma-generated particulate contamination in chip manufacturing processes.
Fig. 11.2 Anatomy of a glow discharge in a long cylindrical tube with plane cathode (C) and anode (A). (a) Various dark spaces and luminous regions are indicated. (b) Sketch of the electric potential \( \Phi \) and axial electric field \( E \) in the normal glow discharge.

The proportionality to \( p^2 \) results from \( E_0 \propto p \), \( d_n \propto p^{-1} \), and \( \mu_i \propto p^{-1} \). Hence, \( j/p^2 \) is a similarity parameter.

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2 Prof. Sanborn C. Brown told the anecdote of the gas-discharge pioneer Wilhelm Hittorf, who attempted to find the maximum length of the positive column [353]. “Week after week his discharge tube grew as he added meter after meter […] His tube went all the way across the room, turned and came back, turned again until his laboratory seemed full of thin glass tubing. It was summer […] and he opened the window to make it bearable. Suddenly from outside came the howl of a pack of dogs in full pursuit and flying through the window came a terrified cat to land […] in the middle of the weeks and weeks of labor. ‘Until an unfortunate accident terminated my experiment’, Hittorf wrote, ‘the positive column appeared to extend without limit.’”
Fig. 11.2 Anatomy of a glow discharge in a long cylindrical tube with plane cathode (C) and anode (A). (a) Various dark spaces and luminous regions are indicated. (b) Sketch of the electric potential $\Phi$ and axial electric field $E$ in the normal glow discharge.

The influence of the tube radius $a$ on the discharge is given by the production-loss balance (4.43), $v_{\text{ion}} = D_a (2.405/a)^2$. Noticing, that $v_{\text{ion}} \propto p$ and $D_a \propto p^{-1}$, we find that the product of gas pressure and tube radius, $p a$, must be a similarity parameter. Similar scalings with $p d$ were discussed for the breakdown voltage, the thickness of the normal glow, and the dimensions of the hollow cathode.

Last not least, the $p d$ scaling explains, why the diameter of fluorescent tubes could be reduced from 1.5" to 1", or even to 1/4" in compact fluorescent tubes, with a corresponding increase in gas pressure, after phosphor coatings were developed that could withstand the increased heat flux. It is also not surprising, that modern gas discharges at atmospheric pressure are tiny objects of sub-millimeter dimensions.
Abstract — Atmospheric-pressure plasmas are used in a variety of materials processes. Traditional sources include transferred arcs, plasma torches, corona discharges, and dielectric barrier discharges. In arcs and torches, the electron and neutral temperatures exceed 3000°C and the densities of charge species range from $10^{16} \text{–} 10^{19}$ cm$^{-3}$. Due to the high gas temperature, these plasmas are used primarily in metallurgy. Corona and dielectric barrier discharges produce nonequilibrium plasmas with gas temperatures between 50–400°C and densities of charged species typical of weakly ionized gases. However, since these discharges are nonuniform, their use in materials processing is limited. Recently, an atmospheric-pressure plasma jet has been developed, which exhibits many characteristics of a conventional, low-pressure glow discharge. In the jet, the gas temperature ranges from 25–200°C, charged-particle densities are $10^{11} \text{–} 10^{12}$ cm$^{-3}$, and reactive species are present in high concentrations, i.e., 10–100 ppm. Since this source may be scaled to treat large areas, it could be used in applications which have been restricted to vacuum. In this paper, the physics and chemistry of the plasma jet and other atmospheric-pressure sources are reviewed.
The conditions are 0.15 torr O₂ and 760 torr N₂. A breakdown occurs at 2500 V at 760 Torr and with a 5 mm gap distance. A narrow gap is necessary to achieve a reasonable breakdown voltage. The breakdown voltage for argon is estimated to be 100 V at 1 torr [13].

The breakdown potential in various gases as a function of the pressure and gap distance is shown in Fig. 1. The graph illustrates the dependence of the applied voltage on current. This relationship is shown in Fig. 2 for a low-pressure DC glow discharge. Shown in Fig. 3 are the results of a relaxation-continuum model. Shown in Fig. 4 are the results of a simulation of the electron and gas temperature as a function of pressure.

In a weakly ionized gas at low pressure, the electron density usually ranges from 10⁻¹⁰ to 10⁻¹⁳ cm⁻³, depending on position. On the other hand, the electron temperature is 10⁵ K, which is much higher, equal to about 0.2 and 2.0 times the ion and neutral temperatures, respectively. Consequently, the electron temperature is insufficient to bring about thermal equilibrium. Consequently, the collision rate between electrons and neutral molecules is much higher, equal to about 0.2 and 2.0 times the ion and neutral temperatures, respectively. The electron temperature increases rapidly with pressure at a constant electrode spacing. For example, the breakdown voltage for argon is estimated to be 100 V at 1 torr [13].

Incident into the operation of a plasma can be obtained from the dependence of the applied voltage on current. This relationship is illustrated in Fig. 2 for a low-pressure DC glow discharge. The plasma can be divided into four regions: 1) the "dark" or "Townsend discharge" prior to spark ignition; 2) "normal glow" where the voltage is constant or slightly decreasing with current; 3) "abnormal glow" where ignition; 4) "arc discharge" where the voltage increases with current.
The discharge can be divided into four regions: 1) the "dark" or "Townsend discharge" prior to spark ignition; 2) "normal glow" where the voltage is constant or slightly decreasing with current; 3) "abnormal glow" where the voltage increases with current; and 4) "arc discharge" where the plasma becomes highly conductive.

Fig. 2. Current–voltage characteristics of a low-pressure DC glow discharge at 1 torr [13].
Insight into the operation of a plasma can be obtained from the dependence of the applied voltage on current. This relationship is illustrated in Fig. 2 for a low-pressure DC glow discharge, showing the dependence of the breakdown voltage on electrode spacing and pressure, are presented in Paschen curves.

The trend in electron and neutral temperatures with pressure is illustrated in Fig. 3 for a plasma discharge with a mercury and rare gas mixture [14], [15]. At 1 mtorr, the gas temperature is 300K, while the electron temperature is 10 000K (1 eV = 6 000K). These two temperatures merge together above 5 torr and are much higher, equal to about 0.2 and 2.0 \(10^{15}\) cm\(^{-3}\), respectively. The concentration of metastable oxygen is constant across the gap, whereas the concentration of oxygen atoms falls to zero at the walls due to surface recombination.

In a weakly ionized gas at low pressure, the electron density usually ranges from \(10^{-10}\) to \(10^{-10}\). Under these conditions, effective energy exchange occurs between the electrons and neutral molecules, so that the collision rate between electrons and neutral molecules is insufficient to bring about thermal equilibrium. Consequently, the electron temperature rises to a point where effective energy exchange occurs between the electrons and neutral molecules, so that for many gases, spark ignition proceeds directly to arcing at 760 torr.

Fig. 3. Schematic of the electron and gas temperature as a function of pressure in a plasma discharge at constant current [14].
A lower production rate of ion-electron pairs. On the lower electron energies at higher pressure (cf. Fig. 3), detected O atom concentrations of about 5 x 10^3 were observed.

Fig. 4. Spatial particle distributions in a parallel plate O\textsubscript{2} RF discharge at \(\omega t = \pi/2\) for \(V_{\text{rms}} = 200\) V [16].

Fig. 5. Time-averaged number densities of each particle in the center of the discharge as a function of pressure in the range between 0.15 and 1 torr [16].
III. TRANSFERRED ARCS AND PLASMA TORCHES

Transferred arcs are used to cut [3], [4], [19], and [20], melt [4] and [21], and weld condensed materials. A schematic of such a device is shown in Fig. 6. It consists of a cylindrical shaped cathode, an outer grounded and water-cooled shield, and a workpiece as the anode. By feeding argon and hydrogen, oxygen, or air between the cathode and shield, and by applying DC power of up to 200 kW, an arc between the electrodes may be ignited and sustained. Typical operation conditions and properties are 1–15 l/s gas flow, 50–600 A, $10^4$ MW/m², gas temperatures between 3000 and 20 000 K, and a nozzle-to-sample distance of 5–10 mm [19]–[22]. These parameters may vary, depending on the nozzle diameter and materials to be cut. Transferred arcs can slice steel plates up to 150 mm thick. For example, a plate, 40 mm thick, was cut at 0.7 m/min with a 600 A arc [23].
torr and thus, a lower production rate of ion-electron pairs. On increases above 0.3 torr, the density of ions diminishes due composition as predicted by Shibata's model. As the pressure of 55 mm and a self bias of 300 V.

detected O atom concentrations of about 5

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V [16]. By comparison,

10

V [17]. By comparison,

of the arc, where they are vaporized and/or dissociated into powder, or volatile molecules, are introduced just downstream processing" [25]. The precursors, in the form of solid pellets, enhance the plasma density and to restrict the cutting area [9].

Transferred arcs can slice steel plates up to 150 mm thick. For vary, depending on the nozzle diameter and materials to be cut.

sample distance of 5–10 mm [19]–[22]. These parameters may gas temperatures between 3000 and 20 000K, and a nozzle-to-

relatively insignificant, so that the chemistry will be dominated in Fig. 5 suggest that at atmospheric pressure, ions will be created by the excitement and dissociation of O

O atoms increases with pressure, because these species are

approximately 99% dissociated with predominantly all of these molecules being converted into O atoms. By contrast, the

magnitude lower. These results are consistent with the energies

magnitude lower. These results are consistent with the energies

an order of magnitude lower at 0.3–0.9 eV. In addition, they

concentrations of O

metastables and

are several orders of

Al

include SiC [26], SiN [27], TiO

[30], and diamond [31]–[36]. The main purpose of these

In transferred arcs and plasma torches, extremely high tem-

A corona discharge appears as a luminous glow localized

field and potential distribution [45]. Fig. 9 shows a schematic

Fig. 9. Schematic of a corona discharge.

Fig. 7 shows the current–voltage characteristics of a plasma torch as a function of the radial and axial positions. Fig. 7. Current–voltage characteristics of an atmospheric-pressure arc.

MW/m

IV. C

Fig. 6. Schematic of a transferred arc apparatus.
and thus, a lower production rate of ion-electron pairs. On and argon RF discharge using two-photon laser excitation. He Selwyn [18] measured the O atom concentration in an oxygen discharge as a function of pressure in the range between 0.15 and 1 torr [16].

Fig. 5. Time-averaged number densities of each particle in the center of the Fig. 4. Spatial particle distributions in a parallel plate O

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For example, Fig. 8 shows the effect of the gas temperature temperatures promote the complete dissociation of the feed gas.

They found that observed electron densities near 3

10 cm

In transferred arcs and plasma torches, extremely high tem-

A corona discharge appears as a luminous glow localized in space around a point tip in a highly nonuniform electric

of the arc, where they are vaporized and/or dissociated into reactive species. The resultant mixture is sprayed onto a

literature, this technique is also referred to as "injection plasma

that are used in thin film deposition [3], [24]–[26]. In the

advanced gas injection schemes are sometimes employed to enhance the plasma density and to restrict the cutting area [9]. Instead of the workpiece. In addition, RF induction coils and

sample distance of 5–10 mm [19]–[22]. These parameters may

gas temperatures between 3000 and 20 000K, and a nozzle-to-

requires electron energies of only 1–5 eV. The trends shown

created by the excitement and dissociation of O

Electrical and electronic fields [37]. Although plasma torches have been considered to be in

ORONA

or CHES

Al

and properties are 1–15 l/s gas flow, 50–600 A, 10

DC power of up to 200 kW, an arc between the electrodes

and a workpiece as the anode. By feeding argon and hydrogen, advanced gas injection schemes are sometimes employed to overcome this problem, two-dimensional arrays of electrodes are used in thin film deposition [3], [24], [29], Y–Ba–Cu–O [24], [29], [259] and weld condensed materials. A schematic of

Fig. 7 shows the current–voltage characteristics of a plasma

corrosion, and oxidation and may also have applications in
tin film deposition. This produces a rapid drop in voltage with increasing current.

example, a plate, 40 mm thick, was cut at 0.7 m/min with a

where they are vaporized and/or dissociated into reactive species. The resultant mixture is sprayed onto a

powder, or volatile molecules, are introduced just downstream of the arc, where they are vaporized and/or dissociated into reactive species. The resultant mixture is sprayed onto a

activate of polymer surfaces [48], [49], and the enhancement

have been developed. Some applications of coronas include the

growth during the thermal oxidation of silicon wafers

Fig. 9. Schematic of a corona discharge.

1687

MW/m

A, the voltage rapidly increases with current. This

Fig. 6. Schematic of a transferred arc apparatus.

Fig. 8. Composition of an oxygen plasma arc at 0.95 atm as a function of the temperature [42].
IV. CORONA DISCHARGE

A corona discharge appears as a luminous glow localized in space around a point tip in a highly nonuniform electric field. The physics of this source is well understood [5], [8], [12], [44]–[47]. The corona may be considered a Townsend discharge or a negative glow discharge depending upon the field and potential distribution [45]. Fig. 9 shows a schematic of a point-to-plane corona. The apparatus consists of a metal tip, with a radius of about 3 μm, and a planar electrode separated from the tip by a distance of 4–16 mm [47]. The

![Schematic of a corona discharge](image)

**Fig. 9.** Schematic of a corona discharge.
shown in Fig. 10 is the dependence of the voltage on the current for a positive point-to-plane corona operating in air at 760 torr [5], [52]. The plasma ignites at a voltage of 2–5 kV and produces an extremely small current of $10^{-10}–10^{-5}$ A. Above $10^{-5}$ A, the voltage rapidly increases with current. This coincides with the generation of micro-arcs, or “streamers,” that extend between the electrodes. A maximum voltage is recorded at about $5 \times 10^{-4}$ A, where the device begins to arc. Coronas are operated at currents below the onset of arcing.

Fig. 9. Schematic of a corona discharge.

Fig. 10. Current–voltage characteristics for a positive point-to-plane corona discharge with a gap of 13 mm in 1 atm of air [5].
V. DIELECTRIC BARRIER DISCHARGE

Dielectric barrier discharges are also called “silent” and “atmospheric-pressure-glow” discharges [6], [54]–[56]. A schematic of this source is shown in Fig. 12. It consists of two metal electrodes, in which at least one is coated with a dielectric layer. The gap is on the order of several mm, and the applied voltage is about 20 kV. The plasma is generated through a succession of micro arcs, lasting for 10–100 ns, and randomly distributed in space and time. These streamers are believed to be \( \sim 100 \) \( \mu \)m in diameter and are separated from each other by as much as 2 cm [6], [56]. Dielectric barrier discharges are sometimes confused with coronas, because the latter sources may also exhibit microarcing.
TABLE I
<table>
<thead>
<tr>
<th>Source</th>
<th>$V_b$ (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-pressure discharge</td>
<td>0.2 – 0.8</td>
</tr>
<tr>
<td>Arc and plasma torch</td>
<td>10 – 50</td>
</tr>
<tr>
<td>Corona</td>
<td>10 – 50</td>
</tr>
<tr>
<td>Dielectric barrier discharge</td>
<td>5 – 25</td>
</tr>
<tr>
<td>Plasma jet</td>
<td>0.05 – 0.2</td>
</tr>
</tbody>
</table>

TABLE II
<table>
<thead>
<tr>
<th>Source</th>
<th>Plasma density (cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-pressure discharge</td>
<td>$10^8$ – $10^{13}$</td>
</tr>
<tr>
<td>Arc and plasma torch</td>
<td>$10^{16}$ – $10^{19}$</td>
</tr>
<tr>
<td>Corona</td>
<td>$10^9$ – $10^{13}$</td>
</tr>
<tr>
<td>Dielectric barrier discharge</td>
<td>$10^{12}$ – $10^{15}$</td>
</tr>
<tr>
<td>Plasma jet</td>
<td>$10^{11}$ – $10^{12}$</td>
</tr>
</tbody>
</table>

TABLE III
<table>
<thead>
<tr>
<th>Source</th>
<th>Density (cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$O^+$, $O_2^+$, $O^-$</td>
</tr>
<tr>
<td>Low-pressure discharge</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>Arc and plasma torch</td>
<td>$10^{15}$</td>
</tr>
<tr>
<td>Corona</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>Dielectric barrier discharge</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>Plasma jet</td>
<td>$10^{12}$</td>
</tr>
</tbody>
</table>

Fig. 18. Comparison of the gas and electron temperatures for different atmospheric-pressure plasmas versus low-pressure plasmas.

In the corona and dielectric barrier discharge, ozone is the main reaction product, whereas in the other plasmas, oxygen atoms represent a large fraction of the reactive species. In a low-pressure glow discharge the concentrations of ions and atoms are lower than in an atmospheric-pressure plasma. However, the impingement rate of these species on a substrate may be about the same in both cases, since the flux to the surface increases with decreasing pressure. Taking into account all the properties of the plasmas, it appears that the atmospheric-pressure plasma jet exhibits the greatest similarity to a low-pressure glow discharge. Consequently, this device shows promise for being used in a number of materials applications that are now limited to vacuum.
Microplasma jet at atmospheric pressure

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A nitrogen microplasma jet operated at atmospheric pressure was developed for treating thermally sensitive materials. For example, the plasma sources in treatment of vulnerable biological materials must operate near the room temperature at the atmospheric pressure, without any risk of arcing or electrical shock. The microplasma jet device operated by an electrical power less than 10 W exhibited a long plasma jet of about 6.5 cm with temperature near 300 K, not causing any harm to human skin. Optical emission measured at the wide range of 280–800 nm indicated various reactive species produced by the plasma jet. © 2006 American Institute of Physics. [DOI: 10.1063/1.2400078]

FIG. 1. (Color online) Schematic presentation of a simple nitrogen microplasma jet device at atmospheric pressure. The inset is the photograph of the microplasma jet at 6.3 lpm N₂.

FIG. 2. (Color online) Photograph of the N₂ microplasma jet in contact with human skin.
Microsecond-pulsed dielectric barrier discharge plasma stimulation of tissue macrophages for treatment of peripheral vascular disease

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Angiogenesis is the formation of new blood vessels from pre-existing vessels and normally occurs during the process of inflammatory reactions, wound healing, tissue repair, and restoration of blood flow after injury or insult. Stimulation of angiogenesis is a promising and an important step in the treatment of peripheral artery disease. Reactive oxygen species have been shown to be involved in stimulation of this process. For this reason, we have developed and validated a non-equilibrium atmospheric temperature and pressure short-pulsed dielectric barrier discharge plasma system, which can non-destructively generate reactive oxygen species and other active species at the surface of the tissue being treated. We show that this plasma treatment stimulates the production of vascular endothelial growth factor, matrix metalloproteinase-9, and CXCL 1 that in turn induces angiogenesis in mouse aortic rings in vitro. This effect may be mediated by the direct effect of plasma generated reactive oxygen species on tissue. © 2015 AIP Publishing LLC. [http://dx.doi.org/10.1063/1.4933403]
B. Microsecond pulsed DBD treatment

Treatment of the aortic rings was performed on glass slides with microsecond pulsed DBD (msDBD) plasma (Fig. 1). Plasma was produced by applying a voltage pulse of approximately 20 kV between the high voltage electrode and a grounded metal plate underneath the slide.\textsuperscript{24,25} Aortic rings were at floating potential. Treatment time and gap distance were fixed at 10 s and 2 mm, respectively, and the frequency was internally controlled. Three frequencies, 50, 830, and 1000 Hz, were used for low, medium, and high plasma treatment. The energy per pulse of a single msDBD plasma discharge was measured and calculated using the methods stated in our previous work.\textsuperscript{26} This was found to be 0.56 mJ/pulse, and the total energy delivered to the cells (dose) during treatment for the three frequencies are 0.3 mJ (50 Hz), 4.6 mJ (830 Hz), and 5.6 mJ (1000 Hz). Tissue was immediately transferred to a 24-well plate well containing matrigel. 

\[ \text{FIG. 1. Photograph of the microsecond-pulsed dielectric barrier discharge generated on top of a glass slide.} \]