A Review on Optimization of DBD based Plasma system for RCS Reduction

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***Abstract*: The concept of radar cross section reduction has become very important subject for the designers giving deep attention to methods of reducing detectability. The low detectability of aircraft from hostile radar sources can be practically achieved through radar absorbing coating (RAM/RAS), shaping, engineered materials or plasma. The techniques such as shaping, RAM coating have bandwidth constraints. Plasma-based stealth also referred to as active stealth technology is an alternative method which is under research. Plasma-based shielding is based on the fact that plasma being dispersive media absorbs the incident electromagnetic (EM) radiation before it is scattered by the target.**

Dielectric Barrier Discharge (DBD) is known to be an efficient technique of plasma generation w.r.t. energy consumption and device complexity. In other words, depending on atmospheric pressure, electron density, plasma frequency, ambient temperature and several other parameters, DBD plasma can behave as an absorber or a reflector of incident EM waves. This paper reviews is upon radar cross section reduction techniques and dielectric barrier used for plasma generation.

***Index Terms*: Radar cross section, plasma, plasma stealth, Dielectric barrier discharge.**

I. INTRODUCTION

The low detectability of aircraft from hostile radar sources can be practically achieved through radar absorbing coating (RAM/RAS), shaping, engineered materials or plasma. The techniques such as shaping, RAM coating have bandwidth constraints. It has been reported that inhomogeneous plasma layer acts as frequency selective medium, and can be used for RF shielding over wide frequency range. In particular, plasma-based stealth also referred to as active stealth technology is still a frontier subject of research. Plasma-based shielding is based on the fact that plasma being dispersive media absorbs the incident electromagnetic (EM) radiation before it is scattered by the target.

Further the plasma-air interface being continuous in terms of electrical dimensions, results in reduced radar signatures as compared to the target surface, which poses a sharp discontinuity for the incident wave. Plasma cloud [1] covering the structure such as aircraft may give rise to other signatures such as thermal, acoustic, infrared, or visual. Thus it is a matter of concern that the RCS reduction by plasma enhances its detectability due to other signatures. This needs a careful approach towards the plasma generation and its EM wave interaction. Further the parameters of plasma that can be controlled to reduce the target detectability, which need to be identified and optimized.

Dielectric barrier discharges (DBDs) are plasmas generators in configurations with an insulating (dielectric) material between the electrodes which is responsible for a self-pulsing operation. DBDs are a typical example of non-thermal atmospheric or normal pressure gas discharges. Therefore DBDs are a relevant tool in current plasma technology as well as an object for fundamental studies.

II. RADAR CROSS SECTION REDUCTION

The concept of stealth or radar cross section (RCS) reduction and control has been a topic of interest since World War II. Attempts were initially made to reduce the detectability of the aircraft by employing wood and other composites as aircraft materials since they were less reflective to the radar waves than a metal. Later shaping and coating [by radar-absorbing materials (RAMs)] [2] emerged as the primary techniques for the RCS reduction (RCSR).The ongoing research on rcs reduction is based on metasurface technology[3], RCSR through shaping is readily apparent in case of stealth fighter aircraft F-22. Alterations in internal construction of the aircraft, use of orthogonal plates, faceting technique, airframe shaping [4]are the various methods used in shaping in aircraft that reduces the RCS. In contrast, RAM coatings have been used since 1950s to achieve low-RCS aircraft design. RAM was also useful in mitigating the coupling effect and cross talk between the antennas mounted on the surface of the aircraft. Techniques such as iron ball paint, foam absorber, split ring resonator absorber, jaumann absorber, carbon nanotube, silicon carbide, grapheme absorber[5] [6],metasurface [7][8] are being used as RAM.

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II. PLASMA BASED RCS REDUCTION

Plasma-based stealth is a radar cross-section (RCS) reduction technique associated with the reflection and absorption of incident electromagnetic (EM) wave by the plasma layer surrounding the structure[9]. Plasma-based shielding is based on the fact that plasma being dispersive media absorbs the incident EM radiation before it is scattered by the target. Furthermore, the plasma–air interface, being continuous in terms of electrical dimensions, results in reduced radar signatures as compared to the target surface, which poses a sharp discontinuity for the incident wave. The use of plasmas to control the reflected electromagnetic radiation from an object (Plasma stealth) is feasible at suitable frequency where the conductivity of the plasma allows it to interact strongly with the incoming radio wave, and the wave can either be absorbed and converted into thermal energy, or reflected, or transmitted depending on the relationship between the radio wave frequency and the characteristic plasma frequency. If the frequency of the radio wave is lower than the plasma frequency, it is reflected. if it is higher, it is transmitted. If these two are equal, then resonance occurs. There is also another mechanism where reflection can be reduced[10].If the electromagnetic wave passes through the plasma, and is reflected by the metal, and the reflected wave and incoming wave are roughly equal in power, then they may form two phasors. When these two phasors are of opposite phase they can cancel each other out. In order to obtain substantial attenuation of radar signal, the plasma slab needs adequate thickness and density.

III. ELECTROMAGNETIC WAVES AND ITS ABSORPTION BY PLASMA

Electromagnetic waves are one of the waves that are propagated by simultaneous periodic variations of electric and magnetic field intensity and that include radio waves, infrared, visible light, ultraviolet, X-rays, and gamma rays. When electromagnetic waves, such as radar signals, propagate into a conductive plasma, ions and electrons are displaced as a result of the time varying electric and magnetic fields[11]. The wave field gives energy to the particles. The particles generally return some fraction of the energy they have gained to the wave, but some energy may be permanently absorbed as heat by processes like scattering or resonant acceleration, or transferred into other wave types by mode conversion or nonlinear effects. A plasma can, at least in principle, absorb all the energy in an incoming wave, and this is the key to plasma stealth. However, plasma stealth implies a substantial reduction of an aircraft's RCS, making it more difficult (but not necessarily impossible) to detect.

The central issue here is frequency of the incoming signal. A plasma will simply reflect radio waves below a certain frequency [12] (characteristic electron plasma frequency). Most military airborne and air defense radars, however, operate in VHF, UHF, and microwave band, which have frequencies higher than the characteristic plasma frequency.

Plasma surrounding an aircraft might be able to absorb incoming radiation, and therefore reduces signal reflection from the metal parts of the aircraft, the aircraft would then be effectively invisible to radar at long range due to weak signals received. A plasma might also be used to modify the reflected waves to confuse the opponent's radar system: for example, frequency-shifting the reflected radiation would frustrate Doppler filtering and might make the reflected radiation more difficult to distinguish from noise.

V. PROBLEMS FACED BY PLASMA

Plasma stealth technology also faces various technical problems. For example, the plasma itself emits EM radiation, although it is usually weak and noise-like in spectrum. Also, it takes some time for plasma to be re-absorbed by the atmosphere and a trail of ionized air would be created behind the moving aircraft, but at present there is no method to detect this kind of plasma trail at long distance. Thirdly, plasmas (like glow discharges or fluorescent lights) tend to emit a visible glow: this is not compatible with overall low observability concept. Last the emission of plasma becomes instable due to the presence of dust particles in the atmosphere. However, present optical detection devices like FLIR has a shorter range than radar, so Plasma Stealth still has an operational range space. Last but not least, it is extremely difficult to produce a radar-absorbent plasma around an entire aircraft traveling at high speed, the electrical power needed is tremendous. However, a substantial reduction of an aircraft's RCS may be still be achieved by generating radar-absorbent plasma around the most reflective surfaces of the aircraft, such as the turbojet engine fan blades, engine air intakes, vertical stabilizers, and airborne radar antenna.

VI. DIELECTRIC BARRIER DISCHARGE

Dielectric barrier discharge is an efficient component in generation of plasma due to its energy consumption and device complexity[13]. The dielectric barrier produces short duration filamentary micro-discharges, but avoids the degeneration into thermal arcs. The micro-discharges create non-thermal equilibrium plasma, where the electric energy is generally used to generate energetic electrons while the gas stays at ambient temperature[14].Dielectric barrier discharges (DBDs) consists of a pair of electrodes separated by a dielectric. One electrode is exposed to the flow and the other is covered. The generated plasma appears to be blue in color. The discharge gap between the electrodes is typically less than 0.1 mm and AC voltage in the kilovolt (kV) range is applied to the electrodes and creates surface discharge plasma on the exposed electrode[15]. The DBD plasma actuators use AC high voltage as an input where the input waveform is sinusoidal. When the applied AC amplitude is high enough so that the electric field goes beyond E_b makes the air ionizes. This ionized air is constantly seen to form above the electrode which is covered by the dielectric.

VII. CONCLUSION

Plasma has been considered as one of the means for regulating the RCS of aircraft-like structures. Even though limited details and data related to plasma-based RCS reduction and control are available, it is known that a few countries have executed plasma stealth in their warfare. The EM wave interaction with plasma primarily depends on the physical characteristics and associated plasma parameters, particularly the plasma temperature and the plasma density. Plasma is electrically conductive over wide range of frequencies and acts as reflector to low frequencies. The use of plasma to control the reflected EM wave and hence, the RCS is possible at greater frequencies, whereas the conductivity of the plasma results in better interactions of plasma and the incident EM wave. The wave is absorbed within the plasma and thus donates toward RCS reduction.

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