The application of plasma microwave interaction on the stealth technology

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Abstract

The plasma stealth is a new interdisciplinary technology on the military application. Because of the complex physical property of the plasma, the plasma stealth can get a much better performance than the traditional stealth technology, such as anti-radar paint and stealthy contour design. The theoretical analysis shows that the larger gradient of the density distribution, lower collision frequency, and higher electron density can enhance the stealth performance. The results of this work can provide many advices for the stealth plasma generator design.

Keywords

Plasma stealth; Plasma-microwave interaction; Radar wave absorption; Plasma scattering.

1. Introduction

Plasma, the forth form of matter, exists in many place of the world and presents in different mode, such as lightning, lamp, fire, stars. And because of the unique physical character of plasma, it can be applied in semiconductor manufacture, material processing, medical device, etc [1]. Considering the aircraft stealth application, the plasma technology is a novel method to reduce the aircraft radar cross section (RCS). The plasma shielded on aircraft can scatter and absorb the incidence radar wave, and can also distort the phase of the waves to disturb the radar detection. Compare to the traditional stealth technology, there are many advantages of plasma stealth [2]. First of all, there are several different mechanisms, such as scatter, absorption, refraction to reduce the reflect radar wave in wideband. Secondly, plasma stealth technology is more economical and available than others. Thirdly, the plasma stealth can applied in different kinds of aircraft without changing the aerodynamic configuration.

Russia (include the Soviet Union) devoted lots of human and financial resources on the research of plasma stealth, and got many achievement in the past decades. Some of the results had applied on the newest flights. This method can make the flight stealthy on the battle field [3].

As early as 1997, the American air force applied a financial support on the “air plasma protect” project. The project is planned to explore one kind of physics mechanism to produce lager area plasma on the aircraft surface with less energy consumed. The density of the plasma can reach 1013cm-3 with 106s living period. There are two different solutions offered by the Stanford University and Princeton University. The scientists of Stanford use the continuous pulse discharge to generate the stable plasma in the atmospheric pressure with the density of 1013cm-3. The solution of Princeton applied physical laboratory is using the electron beam to generate the high density plasma. This solution costs less energy than that of Stanford [3].

The RAMC experiment carried out by NASA is focused on the microwave transmission property of the plasma covered on the reentry aircraft. The plasma diagnostic results of the blunt-end reentry experiment are shown in figure 1. In the diagnostic results show that the plasma covered the surface can disturb the radio communication between the aircraft and the base station, and increase the aircraft stealth performance.

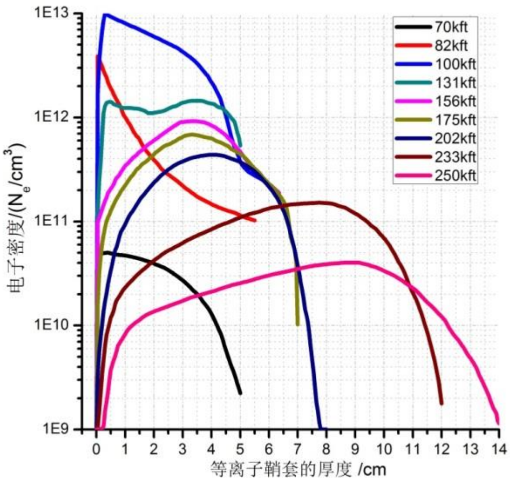

Fig. 1 RAMC plasma density distribution results of different altitude

In this paper, we do some theoretical study on the plasma stealth property, by discussing the complex physical process, such as microwave refraction, plasma scattering, and absorption.

2. The Theory of Plasma Stealth Technology

Plasma is a kind of high frequency attenuator. The plasma can reduce the Radar cross section (RCS) of the aircraft by different processes, such as refraction, collision absorption, resonance absorption, electron scattering, and Faraday rotation et al.

When the frequency of the input radar wave is less than the plasma frequency, the plasma can reflect the microwave. When the frequency is beyond the plasma frequency, the microwave can pass through the plasma. There are three different ways to accomplish the stealth effect by reducing the reflection amplitude of radar waves which illuminate on the plasma:

1, the electromagnetic wave with the frequency greater than the plasma frequency can excite the motion of charged particles. The collisions of the particles can dissipate the energy which absorbed from the input electromagnetic wave.

2, the electromagnetic wave with the frequency less than the plasma frequency cannot penetrate the plasma, and scattered. This changes the transmission direction of the electromagnetic wave to avoid illuminating the target.

3, the path of the incidence electromagnetic wave can be altered in the inhomogeneous plasma. The abnormal transmission path reduces the illuminated area of the target to reduce the radar cross section (RCS).

The microwave get though the collisionless plasma without attenuation, be reflected at the inhomogeneous place, and change the direction of the input radar wave. Because the refractive index of plasma n is less than 1 ($\omega > \omega_p$), the transmission path of the radar wave is bent outward. This phenomenon can reduce the interaction between the targets and microwave of radar.Obviously, the plasma with proper design of plasma density distribution can reduce the RCS by reflection, scattering, or refraction the radar wave. By these ways, the plasma can alter the direction of the radar wave to reduce the radar cross section of the target.

The plasma can also absorb the input radar waves, including ordinary absorption and extraordinary absorption. The ordinary absorption is the collision absorption. The input radar wave accelerates the electron and the kinetic energy of the electron is exhausted by the collisions, such as electron-neutron and electron-ion impact. The extraordinary absorption is the wave interaction of the electromagnetic wave and the plasma. This can transmit the energy from the radar wave to the plasma wave, including the resonance absorption, turbulence absorption, and decay mode absorption et al. Figure 1 shows the principle sketch of the plasma and radar wave interaction.

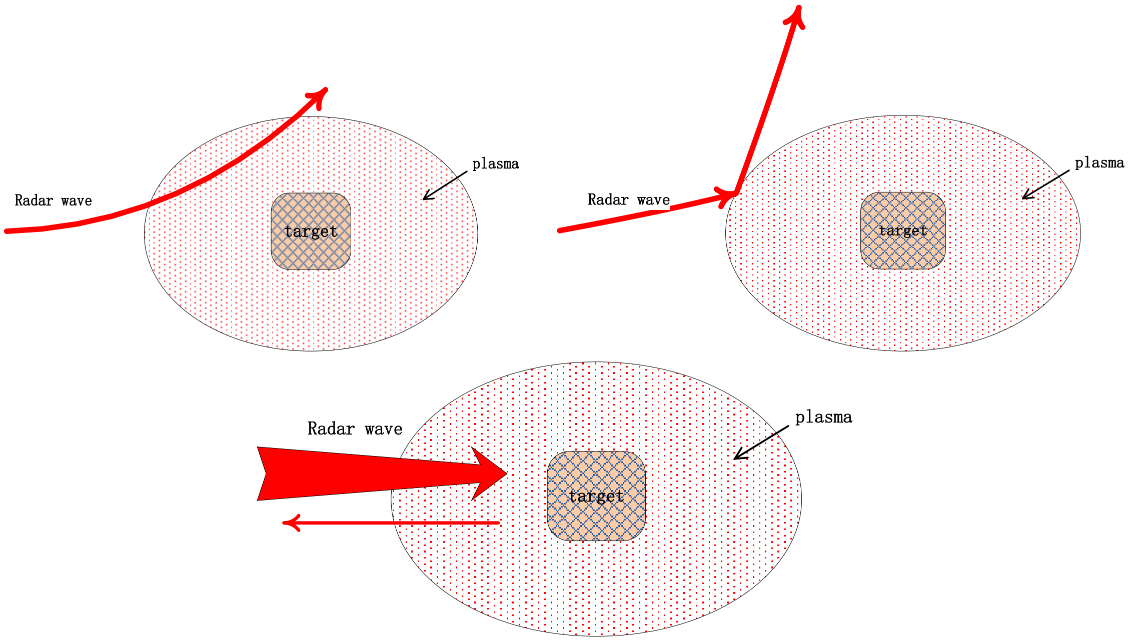

Fig. 1 the principle of plasma stealth technology, scattering, reflection, and absorption

3. Scattering of the Inhomogeneous Plasma

The radar wave is scattered by the inhomogeneous plasma. By changing the transmission direction of the radar wave, the plasma can reduce the RCS of the target dramatically. We suppose the target which is a round metal broad with the radius of 0.1 meter. The density of plasma which covers the round metal broad is n_0 at $R= R_0$. Because of the ambipolar diffusion, the density decreases towards two sides of $R= R_0$. In order to simplify the model, we set the density decreases to 0 at radius of R_1=0.2m and R_2=0.08m, and the distribution of plasma like a spherical shell. The sketch of the plasma scattering model is shown in figure 2.

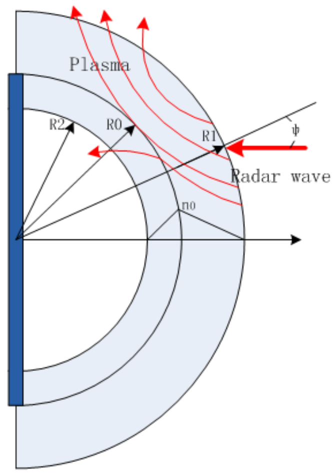

Fig. 2 the sketch of plasma scattering model

We simplify the plasma distribution to the following equations [5,6].

$$n_e(z)=\begin{cases} n_0\dfrac{r\text{-}R_2}{R_0-R_2} & R_2\le r\le R_0 \\ n_0\dfrac{r\text{-}R_1}{R_0-R_1} & R_0\le r\le R_1 \end{cases} \tag{1}$$

The refraction index of the inhomogeneous plasma can be represented as:

$$n=\sqrt{1-\frac{\omega_p^2}{\omega^2}}=\sqrt{1-\frac{n_e e^2}{\varepsilon_0 m_e \omega^2}} \tag{2}$$

Considering the radar wave's transmission property and the Fermat principle, the two equations above can be written as:

$$r\frac{d^2r}{d\theta^2}-2.5\left(\frac{dr}{d\theta}\right)^2-1.5r^2=0 \tag{3}$$

By solving the equation (3), we can get the radar wave transmission equation [2]:

r3/2sinψ=R13/2sinψ0 (4)

The electron density is less than the $n_e(R_0)$ in the region $R_2 \le r \le R_0$. When the radar waves transmit to the spherical surface $R=R_0$, the radar waves can get though the plasma and reach the target covered by the plasma, just like the light propagate in the lens.

Set the ψ=90°、$r=R_0$, by solving the equation (4), we can get the threshold condition of the radar waves reach the target. The threshold condition is shown below:

$$\varphi_0=\arcsin\left(\frac{R_0^{3/2}}{R_1^{3/2}}\right) \tag{5}$$

Geometrically, the radar waves illuminate in the round area with a radius $a=\frac{R_0^{3/2}}{R_1^{1/2}}$ can transmit though the inhomogeneous plasma and arrive on the surface of the target.The RCS of the target covered by the inhomogeneous plasma can be represented as [7]:

$$\sigma=\frac{4\pi r^4}{\lambda^2} \tag{6}$$

Comparing the radius of the target ($R=R_0$) and the illuminate radius ($R=a$), the inhomogeneous plasma can decrease the RCS of the target to $\frac{R_0^6}{R_1^6}$, which is 18dB in our model.

4. Collision Absorption of the Plasma

The radar waves penetrate into the plasma can force the charged particles, especially the electron, to vibrate. And the collisions of the particles dissipate the energy of the radar waves. In the collision plasma, we can use the microwave interferometer to diagnose the phase and amplitude of the radar waves in the plasma. The phase and amplitude changing in the plasma can be represented as the following equations.

$$\Delta\varphi=\int_0^L \beta dx,\qquad \Delta A=\int_0^L \alpha dx \tag{7}$$

The α and β can be written as [8, 9]:

$$\beta = \frac{\omega}{c}\left\{\frac{1}{2}(1-\frac{\omega_p^2}{\omega^2+\nu^2})+\frac{1}{2}[(1-\frac{\omega_p^2}{\omega^2+\nu^2})^2+(\frac{\omega_p^2}{\omega^2+\nu^2}\frac{\nu}{\omega})^2]^{1/2}\right\}^{1/2}$$
$$\alpha = \frac{\omega}{c}\left\{-\frac{1}{2}(1-\frac{\omega_p^2}{\omega^2+\nu^2})+\frac{1}{2}[(1-\frac{\omega_p^2}{\omega^2+\nu^2})^2+(\frac{\omega_p^2}{\omega^2+\nu^2}\frac{\nu}{\omega})^2]^{1/2}\right\}^{1/2} \tag{8}$$

In the high collision frequency plasma, $\nu_{eff} >> \omega > \omega_p$, the equation (8) can be written as [10]:

$$\beta = \frac{\omega}{c}\left\{\frac{1}{2}+\frac{1}{2}\left[1+\frac{\omega_p^4}{\omega^2\nu_{eff}^2}\right]^{1/2}\right\}^{1/2} \approx \frac{\omega}{c}\left[1+\frac{\omega_p^4}{8\omega^2\nu_{eff}^2}\right]$$
$$\alpha = \frac{\omega}{c}\left\{-\frac{1}{2}+\frac{1}{2}\left[1+\frac{\omega_p^4}{\omega^2\nu_{eff}^2}\right]^{1/2}\right\}^{1/2} \approx \frac{\omega_p^4}{2c\nu_{eff}} \tag{9}$$

The amplitude attenuation in the inhomogeneous plasma is:

$$A = \int_0^L \alpha dx = \frac{\omega}{c}\int_0^L \frac{\omega_p^2}{2\omega\nu_{eff}}dx = \frac{e^2}{2\varepsilon_0 mc\nu_{eff}}\int_0^L n_e(x)dx \tag{10}$$

In the plasma density distribution model, we discuss in the section 2, the radar wave absorption effect of the plasma changed with effective collision frequency veff is shown in the figure 3. Different curves represent different maximum electron density.

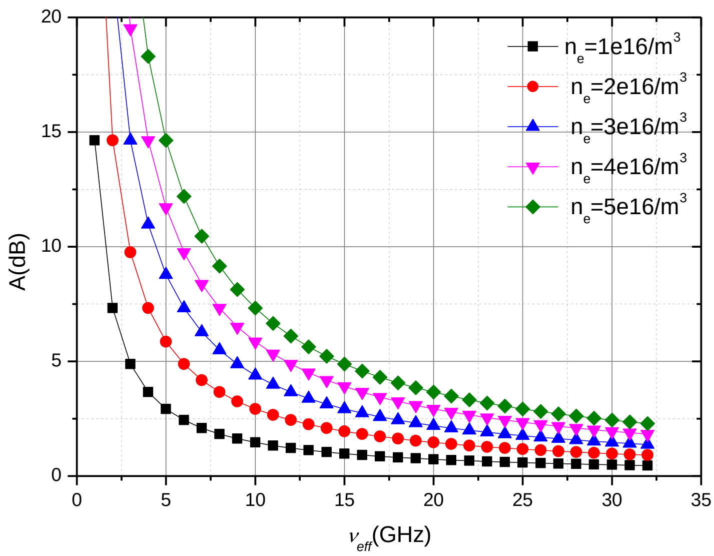

Fig. 3 relationship of the amplitude attenuation and effective collision frequency

As the collision frequency increases from 0.5GHz to 5 GHz the amplitude attenuation decreases significantly. When the collision frequency high than 5GHz, the attenuation decreases much slowly as the collision frequency increases. And the amplitude attenuation increases as the electron density increases. The results of our discussion can supervise the stealth plasma generator design.

5. Conclusion

In this work, we review the plasma stealth technology and discuss the principle of the plasma stealth by introducing the interaction of plasma and radar waves. The theoretical study results show that the scattering and absorption in the inhomogeneous plasma can reduce the RCS of the target. We can get the better performance by choosing the proper density distribution design and the parameters of the plasma generator, such as collision frequency and electron density. The theoretical results show that the larger gradient of the density distribution, lower collision frequency, and higher electron density can enhance the stealth performance.

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