Effect of reactor parameters on matching properties of microwave discharge in liquid

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Abstract. In the paper, the effects of physical and chemical liquid properties in the reactor on matching properties of microwave discharge are studied. The liquid in the reactor is water or water solution; the effects of pH, pressure, conductivity, size of bubble over the inner electrode, water temperature on the standing wave ratio (SWR) are analysed using vector network analyzer. The results show that the SWR increased from 1.512 to 2.623 as the water temperature rose, and the SWR increased as the bubble around the inner electrode grew, while the pH, pressure and conductivity had no effects on the SWR. The main cause for the change of the SWR is the change of the dielectric constant of liquid.

1. Introduction
Plasma is the fourth existence state of materials, and it is widely used in the field of environmental protection and material synthesis, as it contains high-energy particles. At present, the main methods of generating plasma include glow discharge, arc discharge, microwave discharge in gas, and so on. Microwave plasma in liquid is a new plasma technology and becomes more and more concerned due to its large spatial distribution and high density of plasma. At present, little international research work of microwave plasma in liquid has been done except Ehime University of Japan, and study on characteristics of plasma and material synthesis is the main research direction [1-6]. The process of generating plasma is affected greatly by matching properties, and physical and chemical properties of the liquid in reactor have great effects on the matching properties of microwave discharge in liquid, but less research has been done to study that at home and abroad.

The Standing wave ratio (SWR) used to indicate that whether the impedance of the antenna and feeder are matched, it is also an important parameter of the efficiency of injected energy and has great significance to study microwave discharge in liquid. The relationship between SWR and reflection coefficient K is as follows:

$$\text{SWR} = \frac{1+K}{1-K}$$

Therefore, when the SWR is too large, it indicates that matching properties are unsatisfactory, so the SWR has great significance to study microwave discharge in liquid. The height and diameter of the inner electrode and outer electrode, dielectric constant of the insulating material between the inner electrode and outer electrode play decisive roles in the matching process of the electrode and feeder. In

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this paper, the effects of the water temperature, pH, conductivity, size of bubble over the inner electrode and pressure on the SWR of microwave are discussed to lay the foundation for the later study of characteristics of microwave discharge in liquid.

2. Experimental methods

Figure 1 is a schematic representation of the plasma reactor. The height and diameter of the reactor are 16 cm, 15 cm respectively. The height and diameter of the inner electrode are 63 mm, 2 mm respectively, and the height and diameter of outer electrode are 56 mm, 8 mm respectively. The insulating material between the inner electrode and outer electrode are the ceramic tube and silicone. The liquid in the reactor is pure water. The SWR is measured by agilent network analyzer. External pressure is controlled in the range of 0-100 kPa by the water circulation vacuum pump. The pH of water is controlled in the range of 2-12 by HCl and NaOH. The water temperature which ranges from 20 °C to 70 °C is measured by the thermocouple. The conductivity is controlled in the range of 0-0.7 ms/cm using anhydrous Na2SO4.

In the process of making electrode, the top of the ceramic tube flushes with the inner electrode as much as possible, because it is conducive to the adhesion of bubbles, even to study the effect of bubbles on the SWR. When the water temperature is 20 °C, the pressure is 100 kPa, the SWR of pure water equals 1.512.

3. Results and discussion

In the process of matching, the entire reactor can be regarded as a complex capacitor. When the proportion of the reactor structure is determined, the change part is equivalent to the dielectric materials in capacitor. The dielectric constant is not only related with materials, but also with temperature and frequency of electric field.

As shown in figure 2, 3, 4, the effects of conductivity, pH, pressure on the SWR rise and fall around the original SWR which is 1.512, and they are entirely within the fluctuation range of the network analyzer, so solution conductivity, pH value and pressure have no effects on the SWR of microwave discharge in liquid. From figure 5, it can be seen that the SWR increases from 1.512 to 2.011 with the increase of the temperature. It indicates that the temperature leads to the change of the dielectric constant which makes the match of the electrode and the feeder get worse.
Table 1. Effect of size of bubble over the inner electrode on the SWR.

| Size of bubble over the inner electrode | SWR  |
|----------------------------------------|------|
| No bubble                              | 1.512|
| Half a bubble                          | 2.012|
| A bubble                               | 9.032|
| In the air                             | 12.165|

4. Conclusions

Based on the study of the effects of temperature, pH, conductivity, size of bubble over the inner electrode and pressure on the SWR, it is found that conductivity, pH and pressure have no effects on the SWR, while the SWR increases with the increase of temperature. The SWR increases as the bubble size increases, and the significant effect on the SWR is not the size of the bubble, but whether the inner electrode contacts with water.

Therefore, in the process of matching the electrode and the feeder in the future, the main parameters that should be considered include the relative dielectric constant of the liquid in reactor and design parameters of the electrode structure, not the pH, conductivity, pressure and temperature.
Figure 6. Photos of size of bubble over inner electrode.
(a): top view of no bubble (b): top view of half a bubble (c): top view of one bubble
(d): side view of no bubble (e): side view of half a bubble (f): side view of one bubble

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