Analysis and Applications of Carbon Dioxide Laser

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Abstract. As the lasers appeared in the last century, scientist made a lot of efforts to discover the properties of them. After decades of research, lasers have become an important part in our daily life today. Lasers with different functions have been used in various fields. The purpose of writing this paper is to make readers understand the laser better. In this paper, there is an explanation of laser at the micro level. Besides, this paper also introduces the construction of RF Wave guide carbon dioxide laser, and analyzes the natures of carbon dioxide laser as well as its different applications. In the end, some recommendations and prospects of the development of the carbon dioxide laser are stated.

1. Introduction
In 1916, Einstein, who was born in Germany, published a paper on radiation quantum theory about laser technology, mentioning the theory of stimulated radiation, after a series of effort and research results made by brilliant scientists like Hertz and Planck. Later, he won the Nobel Gold Prize for this paper in 1921. However, it was not until 1960 that the young scientists of the American Hughes Company made the first laser, which formed a worldwide laser boom. In this trend, the carbon dioxide laser was developed rapidly[4]. It has experienced the development changing from DC discharge excitation to RF discharge excitation in the discharge excitation mode, the latter of which is used nowadays. Besides, it also changed from single wave guide structure to wave guide array structure, and area increase ratio and volume increase ratio technology in the wave guide structure for adapting the needs of high power and miniaturization[3]. As the technology of carbon dioxide laser getting mature, it is used in various fields like industry, medicine and agriculture, which promote human’s spiritual civilization and material civilization and facilitate people’s daily life as well as bring humanity to a new height.

2. Analysis of the carbon dioxide laser

2.1. The generation of laser
It is known that there are nucleus and electrons in the atom. And atoms can be in different states of excitation. If a lot of energy is applied to an atom, the electron of which can absorb the energy and then leave the ground-state energy level and go to an excited level. In fact, electrons in the high-state level will return to the ground-state level, meanwhile the equal amount of energy will be released and this part of energy will be released in the form of photons.

There is a method called stimulate emission, which means if a photon should encounter another atom that has an electron in the same excited state, stimulated emission can occur. The first photon can stimulate or induce atomic emission so that the subsequent emitted photon vibrates with the same frequency and direction. Thus, if this method is used, we can get the light that is monochromatic, coherent and directional, which is the laser[7].
2.2. Construction of RF Wave guide carbon dioxide laser

Common RF Wave guide carbon dioxide laser has some parts as figure 1 shows[6]. Laser head can be connected with output mirrors that are made in specific materials. The RF power is connected to the RF feed-in end to perform RF excitation on the laser. The gas bottle contains the carbon dioxide, which can be pumped in to the laser cavity when the laser works. In fact, in order to confirm the normal operation of the laser, the laser cavity needs to stay in vacuum. Thus, it is necessary to have a molecular pump to make the cavity turn into vacuum before adding the carbon dioxide. During the research process, it is found that the carbon dioxide laser has a maximum specific output upper limit. The main reason is the temperature rise effect during the operation of the laser. When the temperature of the gain substance of the carbon dioxide laser reaches a certain value, the gain drops quickly. Therefore, an effective cooling method must be adopted to maintain the temperature of the working gas below 500K. Thus, there is a cooling system, which can take the way of gas cooling or liquid cooling[3].

Besides, the reason that we adopt the wave guide cavity is that the structure of the wave guide cavity can make the laser mode volume better match the gain medium activation area compared with the case of an open stable cavity, so that the discharge aperture can be reduced, thereby creating conditions for the diffusion cooling method. It is also beneficial to decrease the temperature of the carbon dioxide gas of the laser.

2.3. Natures of carbon dioxide laser and factors influencing the power

The carbon dioxide laser belongs to the infrared band and can generate a great amount of heat, which is used in various applications as a main property. Besides, under many conditions, it is necessary to control the output power of the laser. There are some factors related to it:

It can be seen from the figure 2 that under the condition with a certain RF input power, the laser output power increases with the addition of the working air pressure at first; and when a certain optimal air pressure value is reached, the output power reaches the maximum; then if the air pressure increases again, the output power will begin to decrease significantly.
In the figure 3, the relationship between the input power and the output power can be attained. Under a certain working pressure, the output power increases with the increase of the RF input power. When a certain maximum value is reached, the output power decreases with the increase of the RF input power. The reason is that when the input power is low, the gain medium is not sufficiently excited, which results in a low output power. However, when the input power is greater than the optimal value and the excessive power is injected, it will result in a reduction in the impedance of the plasma medium and affecting the output power. Conversely, if the radio frequency input power is too high, it will lead to an increase in the temperature of the working gas, which also has a certain effect on the reduction of the output power.

Apart from the output power, the photoelectric conversion rate is also an important indicator.

From the figure 4 it can be seen that under a certain working pressure, photoelectric conversion rate varies with the RF input power, but no matter what kind of air pressure, the photoelectric conversion rate reaches its maximum when the input power is about 100W[5].

2.4. Applications of carbon dioxide laser
In recent years, super-pulsed carbon dioxide laser has been widely used in medical and aesthetic fields. For example, the super-pulse CO2 laser is used for wrinkle removal. The principle is to use the laser to vaporize the epidermis and superficial dermis of the wrinkle area, to tighten the skin and generate collagen fibers in the dermis. However, laser wrinkle removal has more advantages compared with chemical exfoliation, such as no bleeding, no splashing blood and tissue debris, and having easy control of depth and range[1].

Besides, carbon dioxide laser is also used in industrial production. The most common application is cutting materials. Carbon dioxide laser cutting uses a focusing lens to focus the carbon dioxide laser beam on the surface of the material to melt the material. At the same time, the cutting gas coaxial with the laser beam blows away the melted material, and the laser beam takes a relative movement with the material along a certain trajectory, thus, a certain shape of slit is formed. Carbon dioxide laser cutting has the characteristics of narrow incision width, high precision, and good surface roughness. The
incision is narrow, the two sides of the slit are parallel and perpendicular to the surface, and the slit is generally welded without further processing[2].

3. Discussion

3.1. Recommendation of optimizing the carbon dioxide laser
In previous studies, it has been found that the gain medium plays a decisive role in increasing the output power of the laser. The research shows that in order to increase the output power of the laser, it is possible to try to increase the volume of the gain medium, and then use the mirror to increase the distance of the optical path in the gain medium. The problem happens when the gain medium length reaches a certain value and the power will no longer increase. At the same time, a wave guide array laser technology is proposed. It can effectively increase the output power. So if we want to further improve the output power of the laser, it is definitely correct to increase as many wave guide units in the wave guide array as possible. Under the condition that there can only be at most 13 wave guide units in each layer of wave guide, and the only way is trying to increase the number of wave guide layers[3]. After adding the wave guide units, as the light beams need to be coupling and coherent to effectively increase the laser power, it is also necessary to improve the optical path system and try new mirror materials to improve the efficiency.

In addition, the temperature of the working gas also greatly affects the size and stability of the output power. However, most of the carbon dioxide lasers in the market only use the method of diffusion cooling. In order to further improve the cooling efficiency, liquid cooling, such as liquid nitrogen, can be added at the same time, which can effectively improve the stability of the output power[5].

3.2. Prospect of applications of carbon dioxide laser
By further optimizing the control of laser emission and the control of the polarization state, operations in some fields can be further improved. For instance, lasers can be used to perform more delicate surgical operations in medicine and make wounds smaller, better and heal faster. In the industry, at present, carbon dioxide lasers are mainly used to cut thicker plates, and thinner plates are generally cut by fiber lasers. However, as long as the carbon dioxide laser is further refined, it will be fully capable of cutting thin plates, and even better than fiber lasers. The most important thing is that carbon dioxide lasers take lower costs than fiber lasers[2].

Besides, carbon dioxide laser will also develop its applications in other fields like agriculture. For example, it has been discovered that plants can be affected when they are irradiated by carbon dioxide laser. With the advancement of technology, and the further improvement in the control of laser frequency and intensity, the development of agriculture can be promoted. For example, it can distort plant chromosomes and produce genetic mutations to cultivate new excellent varieties.

4. Conclusion
This paper mainly introduces the generation of the laser and explains why the laser is so special, showing the properties compared with light. Besides, this paper focuses on the carbon dioxide laser, including its properties, its structure and some of its applications. Meanwhile, some suggestions for improvement and prospects for the future development of carbon dioxide lasers are put forward. In future scientific research, the author will continue to follow up the study and exploration of laser, and keep on thinking about how to use laser better to improve quality of life.

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