

DC discharge characteristics and fluorine atom yield in NF_3/He

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DC discharge characteristics of NF_3/He have been investigated experimentally under different experimental conditions, for example, different electrode materials, separations, flow rates of the gas NF_3 or He, and series resistances. The optimum discharge parameters and the fluorine atom yield from the DC discharge of NF_3/He as function of load power are studied experimentally.

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Yang *et al.*^[1] reported the nearly resonant energy transfer from metastable $\text{NCl}(a^1\Delta)$ to atomic iodine in 1990. The concept of $\text{NCl}(a^1\Delta)/\text{I}$ as a newly possible laser system is becoming a hot point. Yang *et al.*^[2] achieved population inversion between $\text{I}(^2P_{1/2})$ and $\text{I}(^2P_{3/2})$ in 1992, Henshaw *et al.*^[3] measured the gain on the 1315-nm transition of atomic iodine in a subsonic flow of chemically generated $\text{NCl}(a^1\Delta)$ in 1999 and subsequently showed an output power of 180 mW from a new energy transfer chemical iodine laser pumped by $\text{NCl}(a^1\Delta)$ at 1315 nm in 2000^[4]. The maximum output power of 15 W was reported in 2003^[5].

Being the source of fluorine atom for chemical lasers, the DC discharge of NF_3/He is applied to all gas iodine laser (AGIL) chemical lasers^[3-5] where the lasing medium is produced indirectly by reacting with fluorine atom.

Therefore, the chemical laser efficiency is determined by the quantity of fluorine atoms to the large degree. But few papers have studied the DC discharge characteristic of NF_3/He and the fluorine atom production. In this paper, the DC discharge characteristics of NF_3/He are investigated experimentally and some V - I characteristics at different experimental parameters are given. Besides, fluorine atom yield from the DC discharge of NF_3/He is studied experimentally and the relationship between fluorine atom yield and the load power is shown.

A silica tube with an inner diameter of 22 mm was used as a DC discharge tube and two electrodes were set at two ends respectively. The mixing gas of NF_3 and He was input at the center of anode ring or the side of the tube while using cooled anode and went out through center of cathode. A capacitance pressure meter was used to measure the pressure of the gas. DC discharge characteristics of NF_3/He were studied under different experimental conditions, such as different electrode materials, distances between the two electrodes, flow rates of the gas NF_3 or He, and series resistances.

We have done many experiments by using aluminium pins (+) and copper ring (-), tungsten pins (+) and copper ring (-), copper ring (+) and copper ring (-),

Mo ring (+) and Mo ring (-), Mo ring (+) and cooled stainless metal (-), cooled stainless metal (+) and cooled stainless metal (-), and cooled oxygen-free copper (+) and cooled stainless metal (-) as anode and cathode, respectively. The results show that copper ring and Mo ring as anode or cathode waste largely and run out of quickly; using cooled oxygen-free copper as anode, the discharge can operate steadily when the current is more than 2 A; the cooled stainless metal as anode and cathode is appropriate because the load power is large, fluorine atom production is high, and discharge is stable at a wider range of current. In addition, it is no difference between round and flat electrodes.

We explored the discharge characteristics and V - I characteristics with electrode distances of 29, 70, 75, 40, 38, 55, 44, 35, 60, 40, 42, 43.5, 40.5, 38, 41, and 45.5 cm and different electrode materials. Meantime, we checked the fluorine atom production by titration method. The results show that the load power is lower and fluorine atom production is less when electrode distance is less than 35 cm; the broken voltage is too high to discharge on this power supply (maximum voltage of 10 kV) when electrode distance is more than 45 cm; the load power and the broken voltage depend on the flow rates of the gases largely.

We studied the discharge characteristics under He flow rates of 30, 15, 10, 5, 3, 1, 0.5, and 0 L/min, and NF_3 flow rates of 0.5, 1, 1.5, 2, 2.5, 3, and 3.5 L/min, respectively. Meantime, we checked the fluorine atom production. The results show that the broken voltage is lower when the He flow rate is larger, so it is easy to discharge, but the load power is less and fluorine atom production is lower also; the broken voltage is higher when NF_3 flow rate is larger, so it is difficult to discharge, but the load power is higher and fluorine atom production is higher also.

We have studied the discharge V - I characteristics at series resistances of 12.5, 6.25, 3.125, 1.56, 0.79, 0.395, 2.096, and 1.99 k Ω , respectively. The results show that discharge operates only at less current under large series resistance; it can work at larger current under less series resistance. The discharge is stable when the resistance is

in the range of 1—2 k Ω .

Figure 1 is the DC discharge V - I characteristic under different experimental conditions. It is shown that the flow rates of the gases and the electrode materials are two dominate factors to V - I characteristic, the series resistance only affects the steady discharge current, and electrode distance affects the broken voltage. It is worth mentioning that the pressure of the tube does not completely depend on the flow rates of gases as shown in Fig. 1, for example, the pressure is higher at the less He flow rates.

Moreover, the load power is not monotony with the current, and there are the maximum points as shown in Fig. 2. The pressure of the discharge tube increased from 12 to 27 torr while current increasing from 1.2 to 3.0 A.

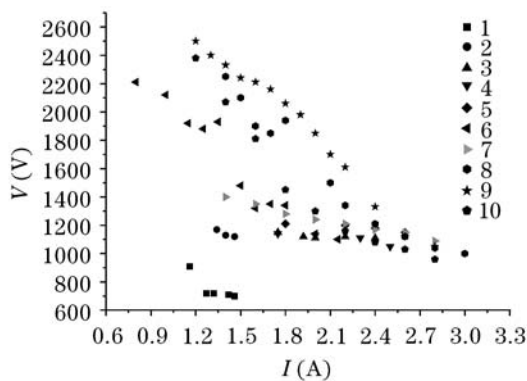


Fig. 1. V - I characteristic of NF_3/He discharge. 1: Cu $d = 29$ cm, $\text{He} = 10$ L/min, $\text{NF}_3 = 0.5$ L/min, $R = 1.56$ k Ω ; 2: Cu $d = 29$ cm, $\text{He} = 10$ L/min, $\text{NF}_3 = 2.0$ L/min, $R = 1.56$ k Ω ; 3: Cu $d = 29$ cm, $\text{He} = 10$ L/min, $\text{NF}_3 = 2.0$ L/min, $R = 0.39$ — 0.79 k Ω ; 4: Mo $d = 70$ cm, $\text{He} = 15$ L/min, $\text{NF}_3 = 0.5$ L/min, $R = 0.79$ k Ω ; 5: Mo $d = 75$ cm, $\text{He} = 10$ L/min, $\text{NF}_3 = 0.6$ L/min, $R = 0.79$ k Ω , $P = 8$ — 14 torr; 6: (+) Mo , (-) cooled stainless metal, $d = 44$ cm, $\text{He} = 5$ L/min, $\text{NF}_3 = 2.5$ L/min, $R = 1.56$ k Ω , $P = 8$ — 12 torr; 7: (+) (-) cooled stainless metal, $d = 60$ cm, $\text{He} = 5$ L/min, $\text{NF}_3 = 1.5$ L/min, $R = 1.56$ k Ω ; 8: (+) (-) cooled stainless metal, $d = 40$ cm, $\text{He} = 1$ L/min, $\text{NF}_3 = 2.5$ L/min, $R = 1.56$ k Ω , $P = 15$ — 21 torr; 9: (+) (-) cooled stainless metal, $d = 40$ cm, $\text{He} = 0$ L/min, $\text{NF}_3 = 2.5$ L/min, $R = 1.56$ k Ω , $P = 13$ — 20 torr; 10: (+) (-) cooled stainless metal, $d = 40$ cm, $\text{He} = 3$ L/min, $\text{NF}_3 = 2.5$ L/min, $R = 1.56$ k Ω , $P = 16$ — 31 torr.

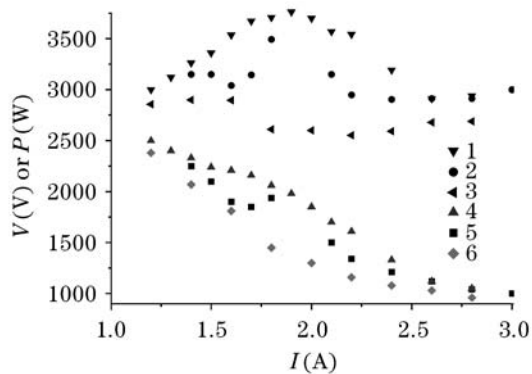
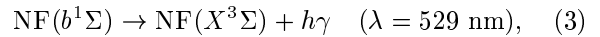
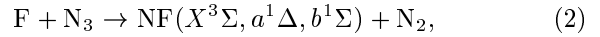
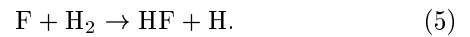
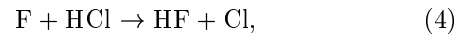


Fig. 2. The relationship of load power P and voltage V with current I . 1: P ($\text{He} = 0$ L/min); 2: P ($\text{He} = 1$ L/min); 3: P ($\text{He} = 3$ L/min); 4: V ($\text{He} = 0$ L/min); 5: V ($\text{He} = 1$ L/min); 6: V ($\text{He} = 3$ L/min). $\text{NF}_3 = 2.5$ L/min, $d = 40$ cm.

Fluorine atom can be measured quantitatively by using titration method. In detail, we can monitor 529-nm emission intensity owing to the following reaction



then using a known flow rate of HCl or H_2 to consume fluorine atom due to the reactions



So the monitored signal intensity decreases with increasing flow rate of HCl or H_2 . And there is an inflexion when the flow rate of fluorine atom is equal to that of HCl or H_2 .

Figure 3 shows titration result. From it we can see that 529-nm emission intensity decreases with increasing the flow rates of H_2 and then trends to a steady number. Fitting linearly for the points before the inflexion, we can use the intercept to subtract the base and find the value

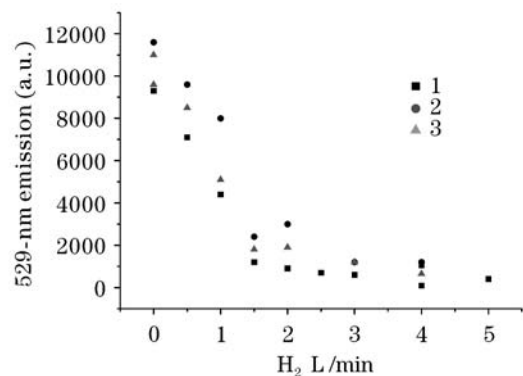


Fig. 3. One group of fluorine atom titration profile. $\text{He} = 7$ L/min, with HN_3 , the distance from the point of test window to the position of HN_3 injection $L = 2$ cm. 1: $\text{NF}_3 = 2.5$ L/min, $I = 1.15$ A, $d = 44$ cm; 2: $\text{NF}_3 = 2.5$ L/min, $I = 1.6$ A, $d = 44$ cm; 3: $\text{NF}_3 = 2.0$ L/min, $I = 1.6$ A, $d = 55$ cm.

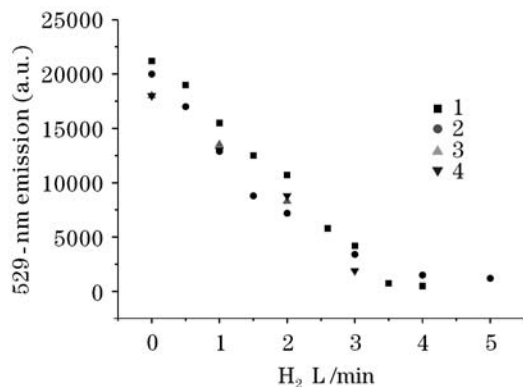


Fig. 4. Another group of fluorine atom titration profile. $\text{NF}_3 = 2.5$ L/min, with HN_3 , $L = 6$ cm. 1: $\text{He} = 1.4$ L/min, $I = 1.7$ A, $d = 40$ cm; 2: $\text{He} = 4.2$ L/min, $I = 1.7$ A, $d = 45$ cm; 3: $\text{He} = 0$ L/min, $I = 1.9$ A, $d = 45$ cm; 4: $\text{He} = 0$ L/min, $I = 1.9$ A, $d = 40$ cm.

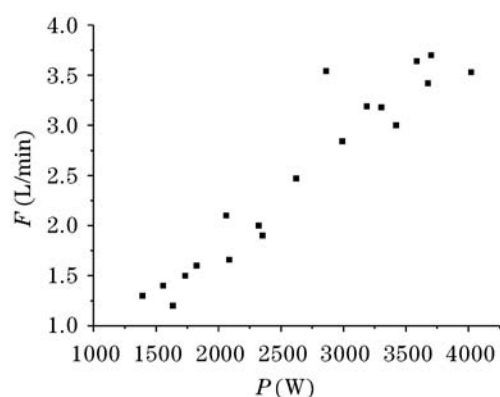


Fig. 5. Relationship of fluorine atom flow rate F and the load power P .

of x axis when y equals zero. Through these processing the fluorine atom flow rates in Fig. 3 can be obtained to be 1.7, 2.5, and 1.7 L/min, respectively. The fluorine atom flow rates in Fig. 4 are 3.7, 3.2, 3.5, and 3.6 L/min, respectively. The results show that the fluorine atom yield is increasing with the increase of the load power as shown in Fig. 5.

In conclusion, we have experimentally investigated the stable discharge and improved the injecting load power. Furthermore, we obtained more fluorine atom yield by DC discharge in which 1.3—1.8 fluorine atoms can be produced from one NF_3 molecule under the conditions of

electrode material of cooled stainless metal, series resistance of 1.56 k Ω , electrode distance in the range of 40—45 cm, current at 1.6—2.2 A, flow rates of He of less than 3 L/min and NF_3 of 2—3 L/min. At these parameters, the maximum load power is 3000—4000 W and fluorine atom flow rate can be up to 3—4 L/min. In the near future, we will use the setup to study AGIL small signal gain based on DC discharge of $\text{NF}_3/\text{He}/\text{DCI}/\text{HI}/\text{HN}_3$ system.

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