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CHARACTERISTICS OF THE AMMONIA BEAM MASER

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ABSTRACT

An ammonia beam maser was constructed and operated. The oscillation characteristics of the maser on ammonia inversion spectrum $J=K=3$ line were observed under various operating conditions. It was found that the oscillation amplitude *versus* focuser voltage characteristics is in good agreement with the theory. Details of the experimental apparatus are described.

1. Introduction

The maser is the amplifier or oscillator, which is opearated on the basis of stimulated emission of radiation. Since the first practical maser was operated utilizing the ammonia beam (**1**), the various masers have been constructed and operated in several laboratories (**2, 3**). The oscillation frequency of the ammonia maser is so stable that it has been studied mainly for the purpose of frequency standard. In this paper, the oscillation characteristics are reported in detail, based on the precise measurement of the oscillation frequency of the maser.

2. Experimental apparatus

The block diagram of the experimental apparatus is shown in Fig. 1. The respective parts are described in the following.

(A) The maser

The vertical cross-sectional view of the maser is shown in Fig. 2. The effuser is made from aluminum wire 0.2 mm in diameter electroplated with copper. After having bunched the wires and cut even at the ends, the aluminum is dissolved out in HCl solution. Thus the effuser consists of a bunch of twenty tubes 0.2 mm in diameter and 6 mm in length.

The eight-pole focuser consisting of steel rods 3 mm in diameter and 355 mm in length, is used. The focuser is insulated with teflon sheets 1 mm in thickness. The focuser radius is 5 mm. The focuser voltage can be applied up to 15 KV.

The resonator is a cylindrical TM_{010} mode cavity, 120 mm in length, and is slotted lengthwise to allow tuning by movable fin. The Q value of the cavity was measured to be about 6,000. The inlet and outlet holes for the beam are 8.5 mm in diameter.

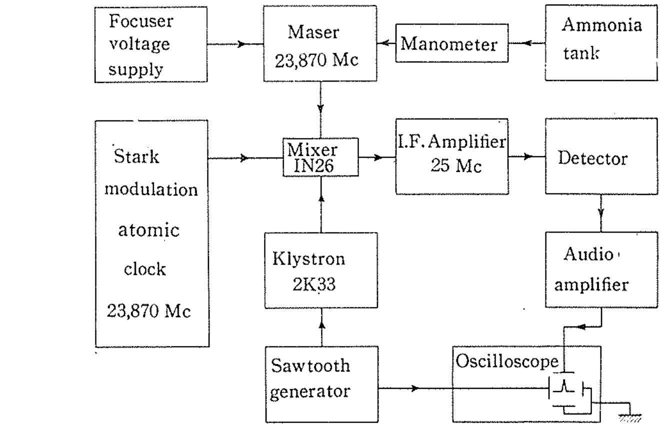

Fig. 1. Block diagram of the apparatus.

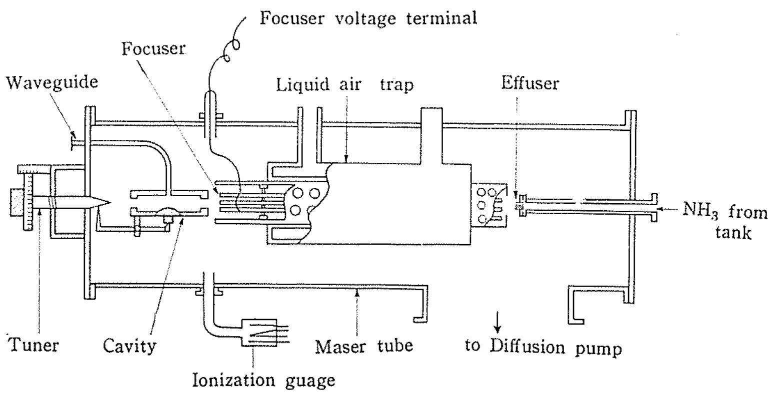

Fig. 2. Cross-sectional view of the maser.

(B) The vacuum system

A 6-inch oil diffusion pump is connected directly to the maser tube. The pumping speeds of the oil diffusion pump and the rotary pump are 800 lit/sec and 800 lit/min respectively. The final vacuum attained without using liquid air trap was measured to be 5×10^{-6} mm Hg. The ionization gauge was used fo vacuum measurement.

(C) The ammonia source

The pressure of the ammonia gas in a tank is reduced by a reducing valve, and finely adjusted by a needle valve. Then the ammonia gas is introduced into a manometer section, where the pressure which is defined as the source pressure is measured. The ammonia gas is effused from the effuser.

(D) The detecting system

The superheterodyne detecting system is employed. A klystron 2K33 is used as local oscillator. As mixer, a best IN26 crystal has been selected out of 10 units. The intermediate frequency amplifier is a four-stage 6CB6 stagger tuned amplifier of the center frequency of 25 Mc/sec. The band-width is about 4 Mc/sec and the maximum gain is about 80 db.

(E) The display system

The oscillation signal, which has been detected and amplified, is displayed on the screen by applying the sawtooth voltage both to the horizontal terminals of oscilloscope and to the repeller of klystron.

(F) The focuser voltage supply

The A. C. high voltage from the step-up transformer is rectified by a rectifier tube 1X2-B. The heater power of 1X2-B is supplied from U. 1. drycell, so that the heater insulation may be easily done. The rectified high voltage is smoothed by R-C filter circuit. The high D. C. voltage is controlled by the slidac connected to the primary of the step-up transformer. Thus we have attained a good performance.

(G) The frequency standard and marker

The Stark modulation atomic clock of absorption type (4) is used for measurement of the oscillation frequency of the maser, referred to JJY (10 Mc/sec), and gives a marker signal.

3. Experimental procedure

(A) Formation of ammonia beam

The vacuum of the maser tube is attainable up to 5×10^{-6} mmHg in about 2 hours after the start of pumping. Then the liquid air is introduced into the trap. When the vacuum has reached 5×10^{-7} mmHg, the ammonia gas is effused through the opening of needle valve. A sharp ammonia beam is obtained in about 15 minutes after the start of effusing.

(B) Adjustment

Before carrying out the observation of the maser oscillation, the microwave circuit and other electronic devices must be adjusted by using the marker from the atomic clock. When the experimental oscillation conditions, which are to be described in the next section 4 (A), are satisfied, the marker is switched off and the maser signal is looked for by slightly varying the cavity tuning.

4. Experimental results

(A) Oscillation conditions

The threshold focuser voltage to start oscillation and the maser tube pressure as functions of the source pressure before effusing through the effuser are shown in Fig. 3.

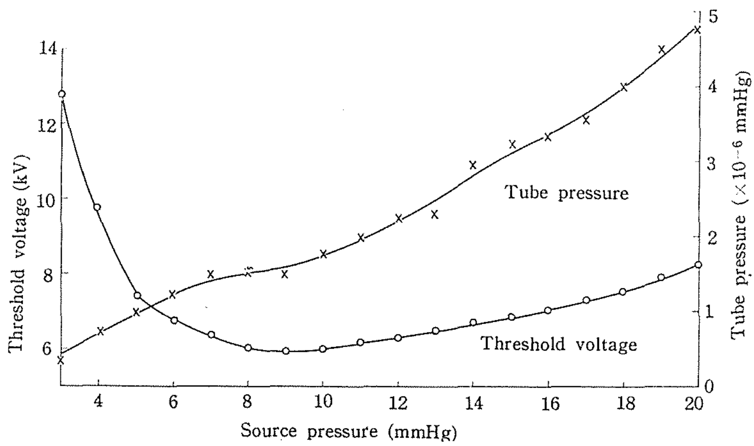

Fig. 3. Experimental oscillation conditions.

The threshold voltage decreases with the increase of the source pressure in a low pressure region, since the beam flux increases with the source pressure. Beyond the optimum source pressure, which is about 9 mmHg in this case, both the threshold voltage and the tube pressure increase with the source pressure. It seems to be due to the collisions among ammonia molecules inside the focuser. The tube pressure is measured by an ionization gauge placed near the cavity.

(B) Oscillation amplitude *versus* focuser voltage characteristics

The oscillation amplitude of the maser *versus* the focuser voltage characteristics have been observed, as shown in Fig. 4.

By the theory, which takes into account the velocity distribution of molecules constituting the beam (5), the oscillation amplitude *versus* the focuser voltage characteristics are expressed as follows:

$$\frac{V_0}{V}=\frac{\sin\{[(\omega-\omega_0)^2+\chi^2]^{1/2}L/2\langle v\rangle\}}{[(\omega-\omega_0)^2+\chi^2]^{1/2}L/2\langle v\rangle},$$

where

$$\langle v\rangle=\frac{\pi L+2l}{4\pi R}\left[\frac{\mu MK}{J(J+1)}\left(\frac{2}{mh\omega_0}\right)^{1/2}\frac{2}{R}\right]V,$$

using the symbols:

V : focuser voltage

V_0 : threshold focuser voltage

χ : oscillation amplitude

μ : molecular dipole moment
J, K, M: quantum numbers
m : mass of molecule
h : Planck's constant
R : focuser radius
ω : frequency of oscillation
ω_0 : center frequency
L : cavity length
l : focuser length

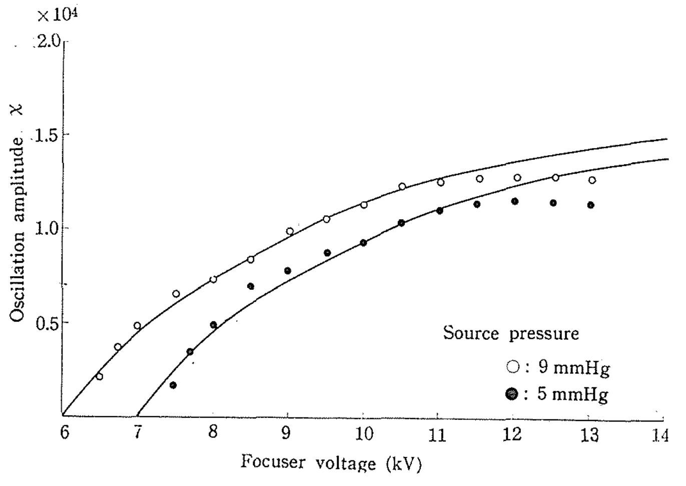

Fig. 4. Oscillation amplitude *versus* focuser voltage.
circles : observed values, curves : theoretical.

In Fig. 4, the scale of the ordinate has been so adjusted as to match the theoretically expected curves. The theoretical curves there are calculated by using the focuser length $l=355$ mm, the cavity length $L=120$ mm, the focuser radius $R=5$ mm and the starting voltages $V_0=6$ KV, 7 KV.

(C) Oscillation amplitude *versus* source pressure characteristics

The relative oscillation amplitude *versus* the source pressure characteristics for various focuser voltages are shown in Fig. 5. The oscillation amplitude increases with the source pressure in a low source pressure region.

Beyond the optimum source pressure, the oscillation amplitude decreases with the increase of the source pressure, while the tube pressure increases with the source pressure. It seems to be due to the collisions among ammonia molecules inside the focuser.

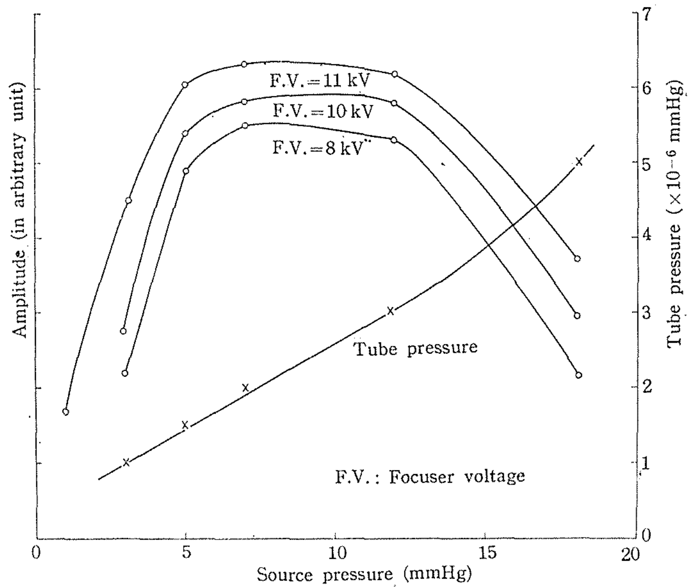

Fig. 5. Oscillation amplitude *versus* source pressure.

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