THE HYDROGEN MASER PROGRAM FOR NAVSTAR GPS

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ABSTRACT

The Department of Defense has assigned to the Navy the task of providing both ground and space maser for NAVSTAR GPS. Two ground masers are being built by the Smithsonian Astrophysical Observatory (SAO) and two contractors, RCA and Hughes, are building preliminary space models. SAO has also succeeded in having a TE_{111} cavity mase. The National Bureau of Standards (NBS) in Boulder is building a passive maser. Supplementary research for this program is being conducted at NRL.

INTRODUCTION

In 1974 the Office of the Director of Defense Research and Engineering of the Office of the Secretary of Defense assigned to the Navy the responsibility of providing hydrogen masers for NAVSTAR ground stations and a space qualified maser for NTS-3 and future satellites. This paper describes the NRL efforts being made to respond to the NAVELEX PME 106 assignment.

The reason for the DDR&E interest in masers is evident from figure 1. Here it is seen that the passive maser is 10 times more stable than the small cesium and the active maser has much better stability than the passive.

A word concerning the status of hydrogen masers. A rough count shows that perhaps 50 such masers have been built and of these about one half are in working conditions. Two fifths of the total number were built by Varian. After the Varian time and frequency functions were bought by Hewlett Packard the Hydrogen Maser portion was given to the Smithsonian Astrophysics Observatory (SAO) located at Harvard Observatory.

Ground Masers

SAO has built 9 ground masers and two space probes. Two of the 9 were delivered to NRL. The one with which I am familiar has worked reliably for more than one year. Initially, it had problems with the dissociator and with the isolation amplifier but since these were fixed, it has operated reliably and well.

SAO is building two improved models for the NAVSTAR GPS program. Initially these units will be used to check out the space masers; ultimately it is planned that they be used at the master control station.

Space Masers

Competitive contracts have been let to two firms, the Hughes Research Laboratory in Malibu, CA, and the RCA Sarnoff Laboratory in Princeton, N. J. These two firms are building advanced development models of the physics packages and experimental development models of the electronics packages. The winner of the competition will then be determined.

Cavities

One of the major problems in the space maser is that of making the unit small. The unit size is determined largely by the cavity size. For the TE_{011} type cavity, almost universally used, the size before loading is approximately 11" in diameter and 11" long. This size is increased substantially by the cavity shell, a pressure vessel, and numerous magnetic shields and heaters.

Another candidate cavity is the TE_{111} which recently has worked in an operating maser at SAO. This cavity is smaller in diameter by a factor of 2.1 than the TE_{011} type and hence less than 1/4 the volume. A paper on this cavity is scheduled for tomorrow's program.

The second method of making a smaller cavity is to load it with dielectric. Mattison of SAO and Folen, Schelling and Lynch of NRL have worked on this problem. Both the TE_{011} and TE_{111} cavities have been solved analytically for most purposes. The TE_{011} is the most interesting of the two. The size of a TE_{011} cavity loaded by a Al_2O_3 is considerably smaller than the unloaded TE_{111} cavity. Figure 2 shows the relative sizes of these devices.

While the loaded TE_{011} is the smallest of the three it does not appear possible to have this cavity work with an active maser. The losses of known dielectrics are at the threshold of oscillation but not low enough to provide a reliable unit. These loaded cavities, then, are as of now suitable only for use in passive masers.

Passive Maser

The passive maser work being supported by this program is one proposed by the National Bureau of Standards at Boulder, Col. This type, of which more will be heard tomorrow, uses the cavity and the hydrogen line transition as a filter, somewhat like the cesium beam is used as a filter in a cesium standard.

The passive maser has an advantage in size in that its operation is not critically dependent on having a specific value of cavity Q. The passive maser can therefore use the dielectric loaded cavity and thereby be made smaller than the active type units.

Maser Problems

So far we have considered the problems of building masers and more especially, small ones. Other problems exist in masers. One is the problem of shielding the cavity from external magnetic fields. Another is related to the darkening of dissociator bulbs. A third concerns bulb coatings. All of these problems not being investigated elsewhere are being looked into at NRL.

In the area of magnetic shielding a shield obtained from SAO was measured for shielding at both high and low level fields. The results of this work by Wolf are shown in figure 3. With the shield used it is apparent that the high level magnetic field shielding is superior to that at low level. Further work, especially with multiple shields, will be performed.

The dissociator, shown in figure 4, has been a source of problems in the early masers. One of the problems has been a darkening of the bulb and a subsequent failure to produce atomic hydrogen. While these problems have been overcome by the use of larger bulbs and better cleaning techniques they are still of interest. Consequently a darkened bulb was obtained for analysis from NASA Goddard. Figure 3 shows the results obtained in Auger equipment by

Ritz, Bermudez and Folen. It is apparent that carbon is a probable villain. Figure 5 shows the atomic fraction of carbon obtained for two samples. An obvious solution, as brought out by JPL, is that a better cleaning method is indicated.

Another problem being supported by non GPS funds involves the bulb coatings. These coatings have been much maligned as possible weak points in maser design. While maligned, the measurements supporting any problem with bulb coating are scarce or non existant. This program is intended to determine if a problem exists in the coatings by measuring both old and new coatings by Auger and ESCA spectroscopy and Attenuated Total Reflection. In addition the use of highly florinated epoxy resins of the diclycidyl class will be evaluated.

Summary

In summary it can be said that the hydrogen maser program for GPS is going well, especially well in the areas which make a small maser appear especially feasible. The TE_{111} cavity has been operated in an operating maser by SAO. The NBS work on the passive maser looks most encouraging, and the SAO-NRL work on dielectrically loaded cavities make a really small hydrogen maser conceptually possible.

Figures

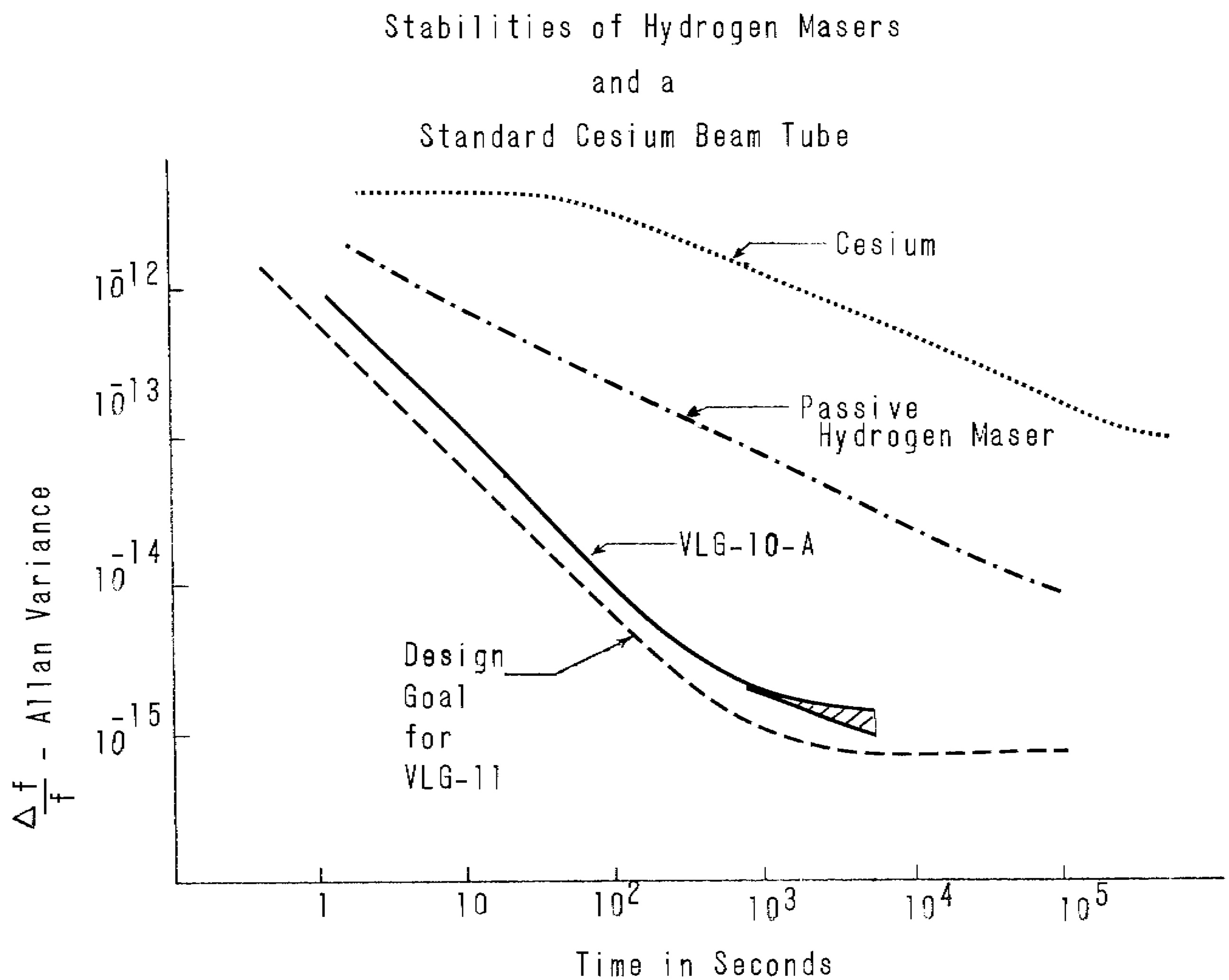

Figure 1 Comparison of Stabilities of Three Hydrogen Masers and One Cesium Beam Tube

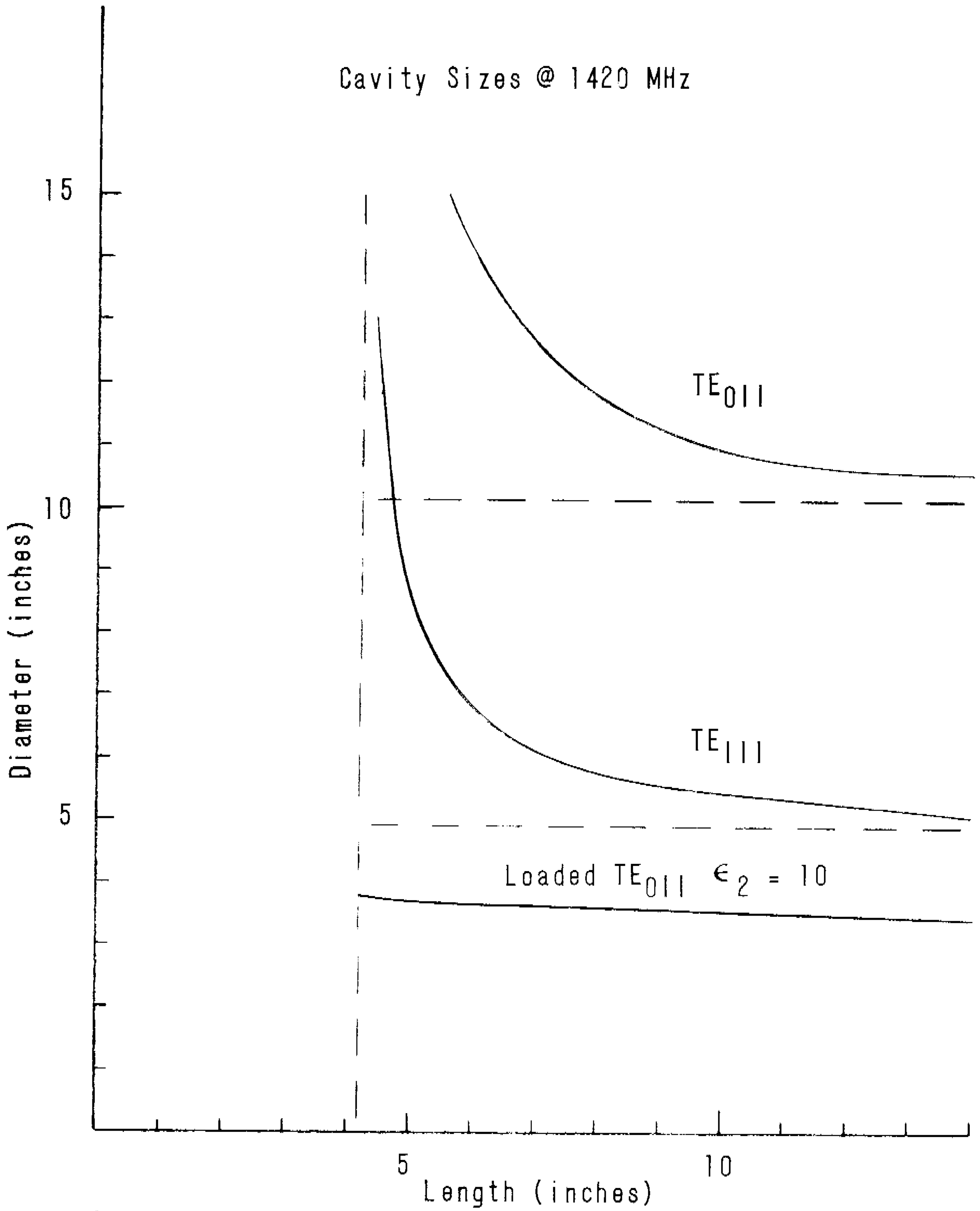

Figure 2 Sizes of Three Types of 1420 MHz Cavities

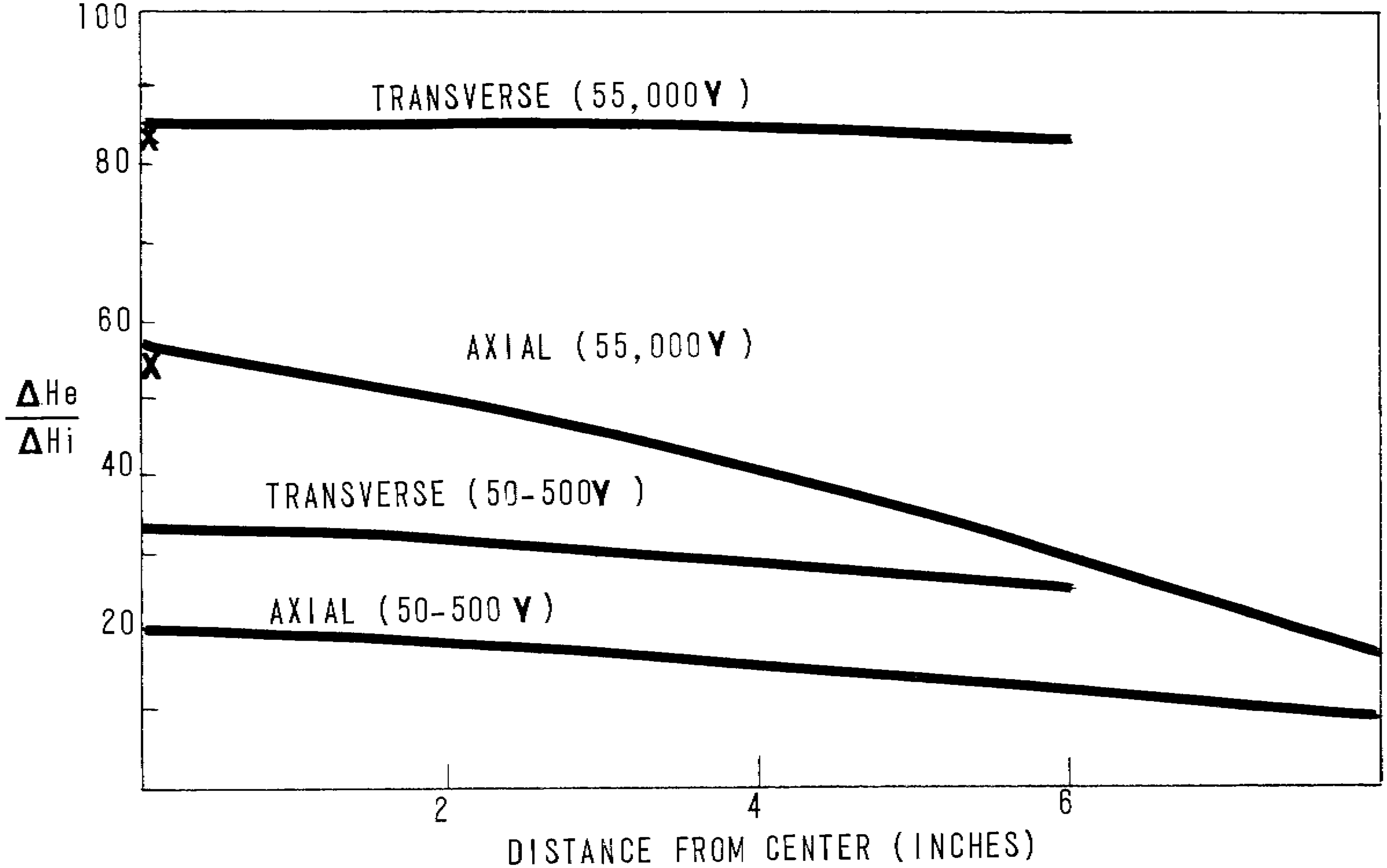

Figure 3 Shielding Factors on 16.6" Diameter Shield (.014" Molypermalloy)
X - SQUID
— Fluxgate

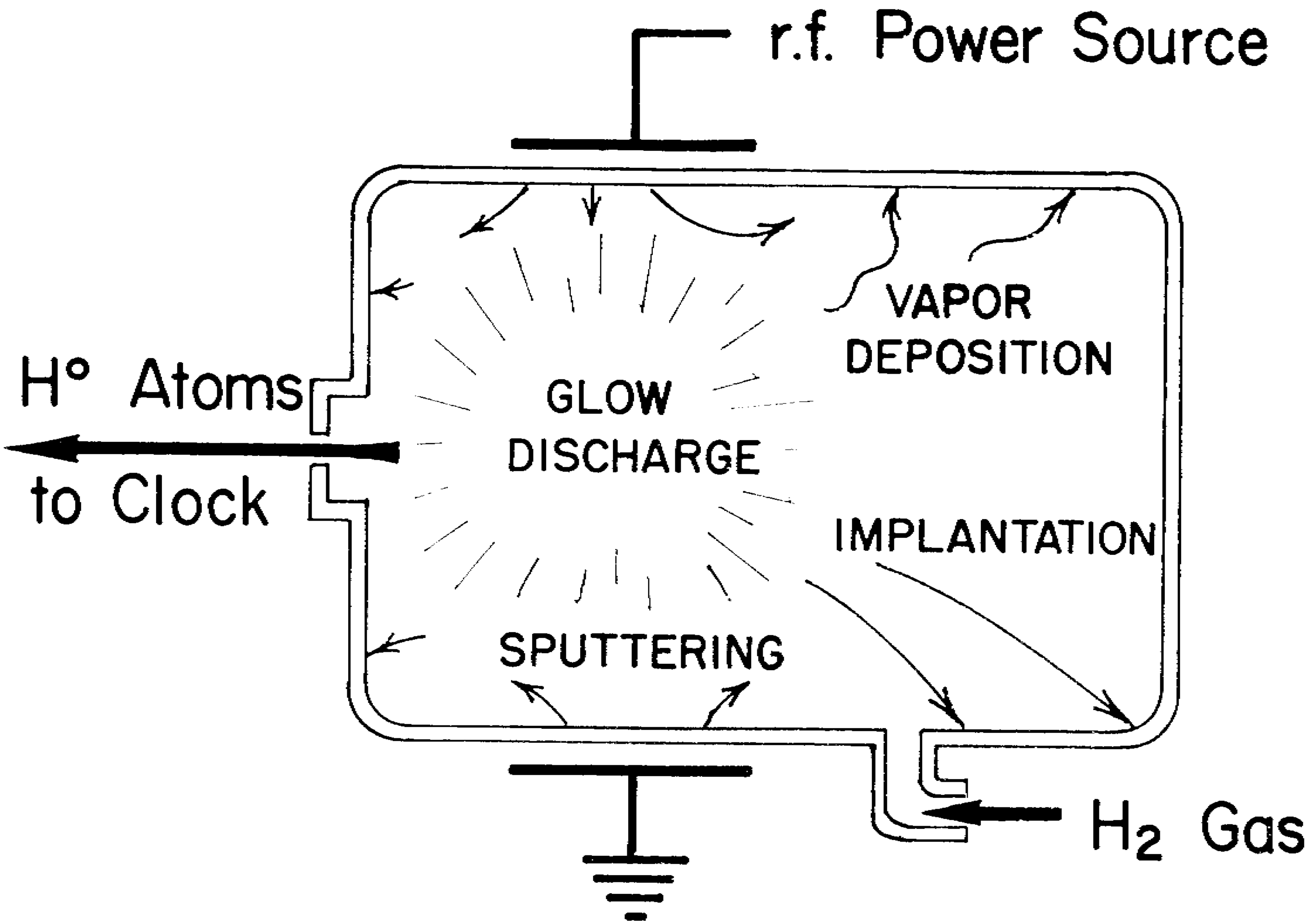

Figure 4 The Hydrogen Dissociator

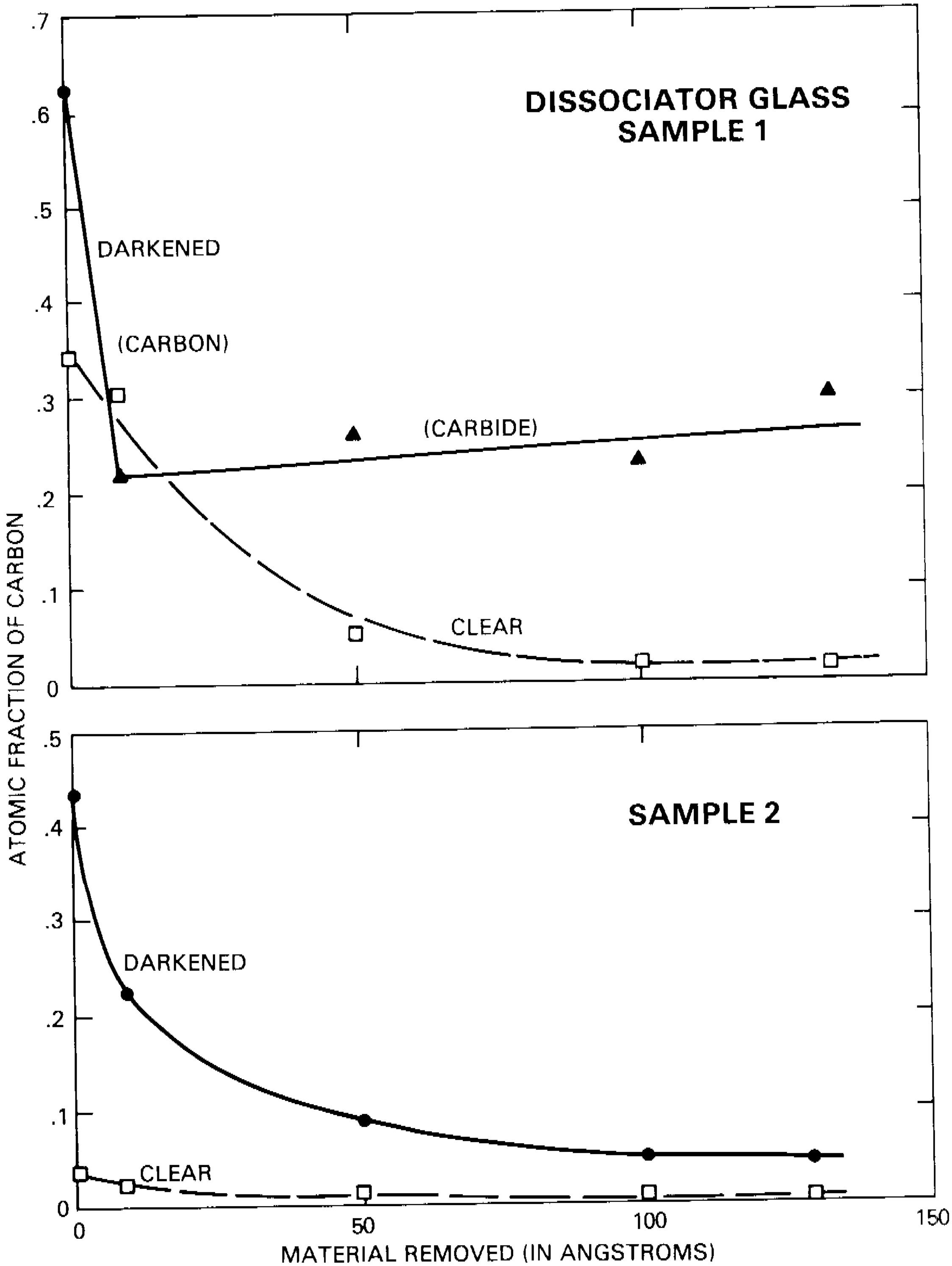

Figure 5 Measurements of Carbon & Carbide on Darkened and Clear Dissociator Glass Samples