Metal hydrides studied in gas discharge tube

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Abstract. A novel construction of gas discharge tube has been tested for production of high
densities of metal hydrydes. Its performance turned out to be comparable with the existing
sources of the same type and even better. First results of the tests on NiH are reported and
critically analysed. Plans for future modification of the construction and application of the tube
are discussed.

1. Introduction
The metal hydrides (especially FeH, CrH, NiH) are among the most abundant molecules that
have been observed in the Sun spots [1, 2, 3] and in the atmosphere of other cold stars [4, 5].
Therefore the knowledge of their absorption spectra is important in order to identify them and
this is one of the motivations for laboratory studies of this molecules. Moreover by using the
Zeeman splitting of the rovibrational energy levels it is possible to make estimations on the
magnetic field on the surface of space objects [6, 7]. The hydrides are specially suited for this,
because their rotational constants are large and it is relatively easy to observe spectra with fully
resolved rotational structure.

Many papers have been devoted to spectroscopic studies of metal hydrides (MH) (see for
example [5, 8] and references therein). There are too main approaches for production of these
molecules in laboratory conditions. The first utilizes a King type furnace and the molecules are
produced by heating the metal up to 2500 - 3000 K in a H₂ containing atmosphere [9]. The
second approach uses gas discharge tubes, where the metal is vaporized by sputtering [10, 11, 12].
The second approach has the advantages of producing molecules at lower gas temperatures (close
to room temperature) with smaller Doppler broadening. The gas pressure is also lower (~ 1 torr
compared with several tens torrs in the King furnaces) leading to smaller pressure broadening.
On the other hand, the collisions with electrons allow higher rovibrational levels of the ground
electronic state to be populated which makes the spectroscopic information more rich.

Some of the existing hollow cathode sources provide relatively high concentration of MH
molecules, but in a small volume [12]. The current densities are high which leads to fast
sputtering of the cathode and requires a cooling. Another construction of gas discharge source
can be found in [10]. It consists of a long tubular cathode and a set of pin anodes placed in the
centre of the tube. It overcomes the disadvantages of the hollow cathode source. It has large
absorption length and less sputtering of the cathode, but the emission from the discharge fills the centre of the tube which makes laser-induced fluorescence (LIF) measurements, for example, difficult.

\[\begin{align*}
\text{Pump} & \quad \text{Ar, H}_2 \\
\text{Vac. gauge} & \quad \text{BS} \\
\text{Discharge tube} & \quad 630-650 \text{nm}
\end{align*}\]

\[\frac{\text{X-Y}}{\text{X}}\]

\[\begin{align*}
\text{DAQ} & \quad \text{PDx} \\
\text{PDy} & \quad \text{Y}
\end{align*}\]

**Figure 1.** a. Scheme of the discharge tube and b. the experimental setup for absorption spectroscopy.

In this paper we present a different design of the discharge tube. It consists of a series of separated ring cathodes and an anode made of several rods forming a cylinder around the center of the tube (Figure 1a). At certain conditions (pressure and discharge current) it was shown that a dark zone is formed in the center of the tube when filled with Ar [13]. This observation motivated us to undertake a systematic study of this tube in order to figure out (i) whether it is suitable for production of high densities of MH and (ii) is it possible to produce molecules at the same conditions when a dark zone is formed in the center of the tube. This would make this tube an extremely attractive source for LIF spectroscopy. The present experiments were carried out with Ni cathodes, because several sources have been tested for NiH production [10, 11, 12] providing good ground for comparison.

### 2. Experimental setup and results

The discharge tube is made of 50 cm long pyrex glass tube. A total of 8 cathodes (a ring made of Ni 0.5 mm foil, 50 mm in diameter and 20 mm thick) are placed. The space between the rings is about 5-6 mm. Each ring is connected separately to the ground of the high voltage (HV) source via a blast resistor of 5.6 kOhm through a glass feedthrough. The anode consists of six Ni rods, 300 mm in length forming a cylinder with a diameter of 30 mm. The tube is closed with glass windows at a small angle with respect to the tube axes (to avoid back reflections to the laser source and interferences). The tube is equipped with two additional glass tube connections, where KF flanges are mounted for pumping out the tube and filling with buffer gas. The DC HV source is able to reach 1.5 kV and currents up to 250 mA. At these conditions and gas pressures down to 100 mtorr of H\textsubscript{2} and Ar we observed a very stable and homogenous discharge between the cathodes and the anodes.

The concentration of NiH molecules was monitored through their absorption in the red B^2\Delta_5/2-X^2\Delta_5/2 band starting from v''=0 in the ground state to v'=0 in the excited electronic B state. This band has been observed already by Brien et al. [11]. The authors give a list of frequencies of identified transitions in two isotopologues – \textsuperscript{58}NiH and \textsuperscript{60}NiH so it should be easy to set the laser to one of the absorption lines. The setup is shown in Figure 1b. The laser source is a commercial free running diode laser (635 nm or 650 nm) scanned in frequency by the current and the temperature. While the main laser beam passes the discharge tube and its
The presented configuration of discharge tube turned out to be a successful alternative of the existing sources for production of metal hydrides. The construction is not limited at length, so long absorption paths can be realized. Additional attractive feature of this tube is that there is no
current in its center and at certain conditions it can be dark. Unfortunately in case of hydrogen at the currents and gas pressures for maximum NiH production the central zone was bright. In parallel to the experiment we run a numerical simulation (a report will be presented elsewhere) which reproduces reasonably the experimental observations. At present we are optimizing the code and we will search for configuration with at least similar MH concentrations and dark central zone. One way is to study discharges in different hydrogen containing gases (for example CH₄, H₂O, NH₃). Another possibility is to change the geometry of the tube. Preliminary calculations and also practical consideration have shown that a dark zone can be achieved even at 200-400 mtorr of H₂ when the diameter of the cathodes is about two times larger. There is still another direction for future application of the new tube. We plan to study the possibility to insert the tube in a magnetic field in order to study the Zeeman splitting of the MH lines (especially FeH).

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