Isotope Shifts of A Titanium IR Line

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We investigated a strong $\Delta J = -1$ (a $^5F_4 \rightarrow z\ ^5D_3$) line of neutral Titanium at 8435,65 Å [1], using a home-made hollow cathode lamp [2] and saturated absorption sub-doppler techniques. A semiconductor laser spectrometer in Littman-Metcalf external cavity configuration [3] enabled us to extract precise isotope shifts and hyperfine splittings constants[4], allowing separation of specific mass and field shift contributions .

INTRODUCTION

Semiconductor Diode Lasers are becoming increasingly flexible tools for spectroscopic investigation. Their wavelenght coverage are extending up to the blue side of the spectrum and down further in the infrared. However solitary diode lasers have some drawbacks as limited tuning range, large linewidth and inacessible spectral regions. These problems could be overcome by adding external elements as mirrors and gratings. Several possible configurations are described in the literature, but the Littman-Metcalf is gaining increased acceptance. We employ this configuration due to its several advantages : use of commercial encapsulated lasers, no need of special coatings and good stability of output beam. A very large passband reduction factor is obtained by the use of a grating in double passage grazing incidence.

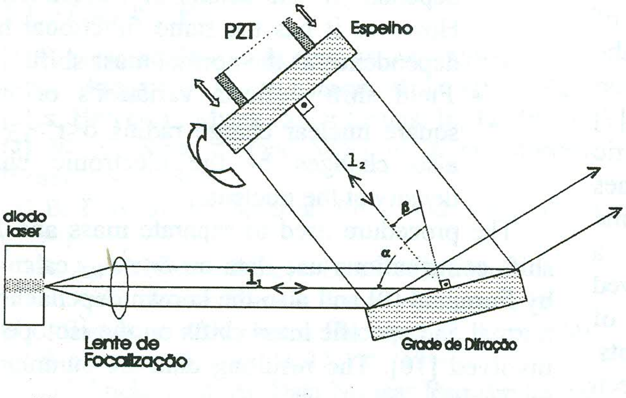

Fig. 1 - External Cavity Semiconductor Laser - Littman Configuration

EXPERIMENTAL

Our light source was a semiconductor laser in the Littman-Metcalf extended cavity configuration [3] seen in Fig. 1 . We use a Mitsubischi ML-5784F diode laser with specified power of 15 mW at 846 nm. The output beam was collimated by a 0.5 NA / f = 8 mm Melles-Griot objective. This beam incides at 80 degree grazing angle on a 1800 l/mm holografic grating. Here we have to trade power for resolution since our grating was not optimized for operation at such large angles. At a typical operating power of 10 mW, we have 25% loss in the grating, 25 % coupled out of the cavity and 50 % coupled in the first diffraction order.

This laser configuration allowed ± 5 nm tuning range and 2.5 mW output power in a stable elliptical beam. Using a good commercial power supply and active temperature control, we estimated a linewidth of 2 MHz. The frequency scale was calibrated by the transmission peaks of a 75 MHz free spectral range Fabry-Perot confocal interferometer.

Titanium, being a refractory element, must be sputtered in a hollow cathode discharge lamp [2] developed for spectroscopic purposes. Typical values of operation was 1 Torr argon pressure and 100 mA electrical current. These conditions produce an $\alpha L = 1$ % total absorption and a measured Doppler width of about 1 GHz. This lamp could be refrigerated for operation at higher currents.

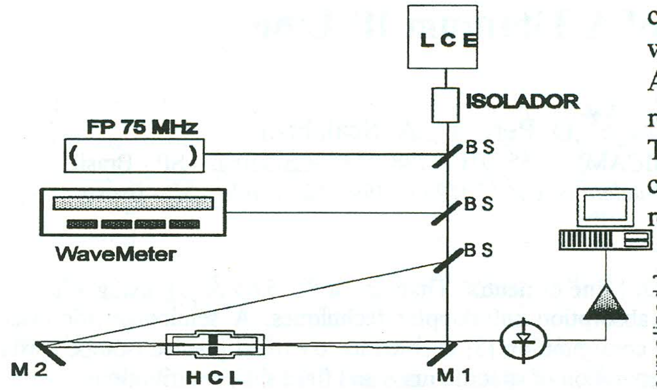

Fig. 2 - Semiconductor Laser Spectrometer. M-mirror, BS - beam-splitter, LCE - Extended Cavity Laser, HCL -Hollow Cathode Lamp.

RESULTS

In Fig. 2 , we can appreciate the very good signal to noise ratio in the saturated absorption spectrum transition **a $^5F_4 \rightarrow$ z $^5D_3$** at 8435,65 Angstroms, obtained at a quite high current of 300 mA. The 40 MHz residual linewidth could not be attributed to the laser beam crossing angle, calculated as 10 MHz, and this must be pressure or collision broadening. Due to the great range of intensities it was necessary to plot data in a logarithmic scale. Hyperfine structure of the odd isotopes 47 (I=5/2) and 49 (I=7/2) are observed on both sides of central isotope 48 [4], partially obscured by the line wings and a broad pedestal of velocity changing collisions [5]. Despite this fact a set of 15 lorentzian curves was least squares adjusted giving good agreement with data.

We obtained directly the even isotope shifts, but for the odd ones we calculated the center of gravity through the position and intensities of the fitted lines. First order hyperfine perturbation energies are given by the Casimir formula [7] through the magnetic dipole A and electric quadrupole B constants. Attributing specific lines by the use of theoretical relations for hyperfine transitions intensities [7], we build a superdetermined equation set that could be solved by least squares adjustment giving the center of gravity and the upper level A_u and B_u constants. Fortunately the lower level parameters have been measured by Atomic Beam Magnetic Resonance by Aydin [6], greatly simplifying the procedure delineated above.

Using magnetic dipole A_l = -70.6 MHz and electric quadrupole B_l =-17.4 MHz hyperfine constants from the isotope 47 lower level a $^5F_4$ [6] we calculated for the upper level z $^5D_3$ the values A_u = -116.5 MHz and B_u = 10.3 MHz . The resulting values for isotope shifts δf are given in Table 1. All these lines shows negative shifts confirming the predictions by Bauche [8] with reasonable agreement.

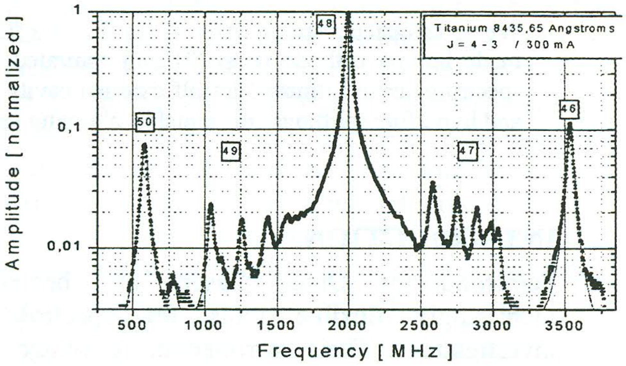

Fig. 2 - Neutral Titanium spectrum line at 8435.65 Angstroms.

SEPARATION OF MASS AND FIELD SHIFTS

Isotope shifts results from several electronic and nuclear contributions. They could be separated with good precision in a sum of 3 factors :

- Normal mass or Bohr shift : arises from the well known reduced mass corrections due to the finite nuclear and electronic mass.
- Specific mass shift: results from correlations between electronic motion, being very difficult to calculate since it depends on fine details of wavefunctions. However it has the same functional mass dependence as the normal mass shift.
- Field shift: reflects variations of mean square nuclear charge radius $\delta\langle r^2\rangle_{1,2}$ and also changes of the electronic charge density at the nucleus.

The procedure used to separate mass and field shift contributions use data on $\delta\langle r^2\rangle_{1,2}$ calculated by Furmann [9] and also the known dependence of normal and specific mass shifts on the isotope pair involved [10]. The resulting data are summarized on Table 1.

Through an statistical analysis we find that the larger error contribution to this separation process comes from the knowledge of the even isotopes total shifts $\delta f_{2,1}$. To reach a point where the error introduced by $\delta\langle r^2\rangle_{1,2}$ becomes equivalent to $\delta f_{2,1}$, the later must have an uncertainty ten times lower (< 0,3 MHz).

Isotope Pair	$\delta f_{2,1}$ [MHz]	δf_N [MHz]	δf_R [MHz]	δf_S [MHz]	δf_F [MHz]
47 - 46	- 786 (5)	90,3 (0,1)	- 876 (5)	- 871 (5)	- 5 (7)
48 - 47	- 749 (5)	86,3 (0,1)	- 835 (5)	- 833 (5)	- 2 (7)
49 - 48	- 731 (5)	83,1 (0,1)	- 814 (5)	- 802 (5)	- 13 (7)
50 - 49	- 686 (5)	79,5 (0,1)	- 765 (5)	- 767 (5)	- 2 (7)
48 - 46	- 1535 (3)	176,6 (0,1)	- 1711 (3)	- 1704 (3)	- 11 (11)
50 - 48	- 1417 (3)	162,6 (0,1)	- 1580 (3)	- 1569 (3)	- 7 (9)

Table 1 - Separation of isotopic shift contributions - line 8435,65 Å.

CONCLUSION

We have demonstrated the use of external cavity semiconductor laser for obtaining high resolution spectra of titanium in a hollow cathode lamp. The isotope shifts and the hyperfine structure were measured. Fitting the data to Casimir formula allowed us to determine the magnetic dipole and the electric quadruple of the upper level. An estimate of the various contributions to the isotope shifts was presented.

Hollow Cathode Lamps are a versatile and cheap way to produce atomic vapour samples of refractory elements for sub-Doppler laser studies. The combination of these two tools opens up the access to spectral regions not possible in earlier studies of titanium, with perspectives of extension to the blue through frequency doubling nonlinear crystals.

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