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Radiative lifetime measurements for some levels in Mn I and Ni I by time-resolved laser spectroscopy

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ABSTRACT

Natural radiative lifetimes for 32 excited levels of Mn I and for 17 excited levels of Ni I were measured using time-resolved laser-induced fluorescence (TR-LIF) spectroscopy in laser-induced plasma. The energy regions are from 45,754.27 to 54,950.81 cm^{-1} for Mn I and from 28,578.018 to 50,851.199 cm^{-1} for Ni I. The uncertainties of all lifetime results are within 10%. To our best knowledge, 26 lifetime results of Mn I and 9 lifetime results of Ni I are reported for the first time.

1. Introduction

Oscillator strengths of atomic or ionic species are required in analyses of astrophysical spectra for elemental abundance estimations. Compared with the methods by absorption or emission spectra which need accurate atomic density, the combination of radiative lifetimes with experimental or theoretical branching fractions is a more reliable method for oscillator strength determination. Recently, the iron-peak elements, especially Mn and Ni, have received much attention in high-resolution spectroscopic analyses for star clusters. Cunha et al. [1] presented Mn abundances in 10 red giant members of the globular cluster ω Centauri. The relative abundance of several chemical elements containing Ni in the old, rich open cluster Trumpler 20 was applied to estimate the cluster age and its distance to Galactic center [2]. The abundances of Mn and Ni for seven bright giants of the globular cluster M62 were determined by Yong et al. [3] for studying the abundance dispersion in galaxy globular cluster M62. In view of this, we perform in the present work some measurements of natural radiative lifetimes of Mn I and Ni I levels.

For Mn I, radiative lifetime measurements of z $^6P_{7/2,\ 5/2,\ 3/2}$ levels were reported by Marek and Richter [4] using phase shift method. Using the beam-foil method, Pinnington et al. [5] measured lifetimes of levels from y $^6P^0$, x $^6D^0$, z $^4H^0$, z $^6F^0$, z $^6D^0$ and z $^4D^0$ terms while Martinson et al. [6] measured lifetimes of levels from z $^6F^0$, z $^6D^0$, e ^6D, z $^2I^0$ and z $^4F^0$ terms. Using delayed coincidence method, Marek [7] published lifetimes for e $^6S_{5/2}$, e $^6D_{9/2,\ 7/2,\ 5/2}$ levels and Becker et al. [8] reported lifetimes for levels from e ^8S, z ^6F, z ^4F and z ^4D terms. With laser-atomic-beam spectroscopy, the hyperfine structure splitting constants and the lifetimes of Mn I levels z $^4P_{3/2,\ 5/2}$ were determined by Kronfeldt et al. [9]. Using TR-LIF technique, radiative lifetimes were reported by Schnabel et al. [10] for 46 levels, by Blackwell-Whitehead et al. [11] for 9 levels form z ^6D, x ^6P and w ^6P terms and by Den Hartog et al. [12] for 22 levels from e ^8D, z ^6P, z ^6D, z ^4F, e ^8S and e ^6S terms.

For Ni I, early radiative lifetime data are the phase-shift results of Marek [13], the Hanle results of Becker et al. [14], the laser-excitation measurements of Heldt et al. [15], the

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delayed coincidence results of Becker et al. [16], the beam-foil measurements of Andersen [17], Brand et al. [18] and Lennard et al. [19], and the derived results from transition probabilities or oscillator strengths of Corliss and Bozman [20], Huber and Sandeman [21], and Blackwell et al. [22]. The extensive Ni I lifetime measurements were performed by Bergeson and Lawler [23] using TR-LIF technique. They reported lifetimes for 66 levels ranging in energy from 29,000 to 57,000 cm^{-1} based on the energy levels compiled by Sugar and Corliss [24]. Recently, based on the energy levels determined by Litzén et al. [25] who expanded the number of energy level from 185 to 286, Johansson et al. [26] measured the lifetime of the 50,276.321 cm^{-1} level.

Although some efforts were devoted to the investigation of Mn I and Ni I, their lifetime data are still fragmentary. In this paper, radiative lifetimes for 32 excited levels of Mn I and for 17 excited levels of Ni I were measured using TR-LIF spectroscopy.

2. Experimental setup

The experimental setup used in this work for lifetime measurements is shown in Fig. 1. Free atoms were obtained by laser ablation on the Mn or Ni target foil which was placed in a vacuum chamber and rotated during the experiment. The ablation laser with 532 nm wavelength, 8 ns duration and about 10 mJ energy, emitted by a Q-switched Nd:YAG laser working at 10 Hz repetition rate, was perpendicularly focused on the Mn or Ni target. In order to obtain the suitable excitation, 532 nm pulses with 8 ns duration, emitted by another Q-switched Nd:YAG laser (Spectra-Physics) working at 10 Hz repetition rate, were sent to pump a dye laser (Sirah Cobra-Stretch) operating the DCM dye. Tunable short wavelength laser pulses were obtained utilizing different nonlinear processes. The frequency-doubling of the dye laser with an about 0.08 cm^{-1} line width was produced by a β-barium borate (BBO) type-I crystal, and then was focused into a hydrogen cell to obtain different orders of Stokes or anti-Stokes Raman-shifted components for obtaining wavelength from 268 to 453 nm. The frequency-tripling by a retarding plate and another BBO type-I crystal was used to obtain wavelength from 201 to 219 nm. Then the excitation laser was sent horizontally through the sputtered cloud of atoms at a distance of about 8 mm above the target surface.

The two Nd:YAG lasers were triggered by a digital delay generator (SRS Model 535) which provided different time intervals between the ablation and excitation pulses. In this work, the delay was changed in the range from 4.5 to 65 μs for manganese atom and from 4 to 30 μs for nickel. The fluorescence decay signal emitted from the excited states under investigation was focused on a grating monochromator (f=10 cm) by a fused silica lens in the direction perpendicular to the excitation laser and the atom plume. The fluorescence signal selected by the monochromator was detected by a photomultiplier tube (PMT; Hamamatsu

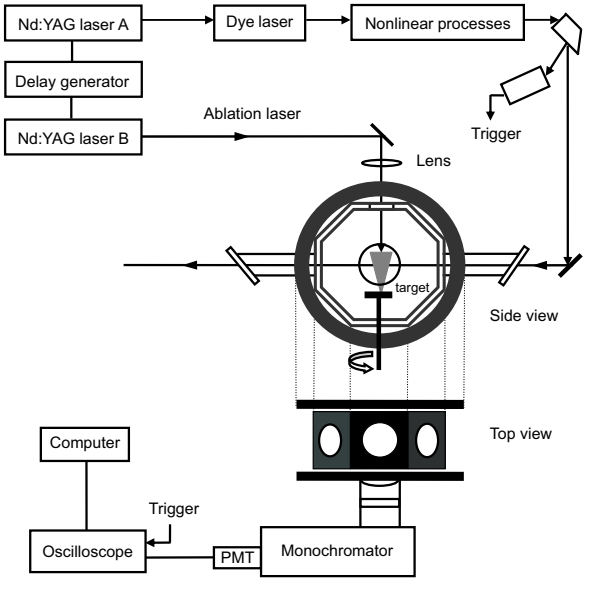

Fig. 1. Experimental setup used for lifetime measurements.

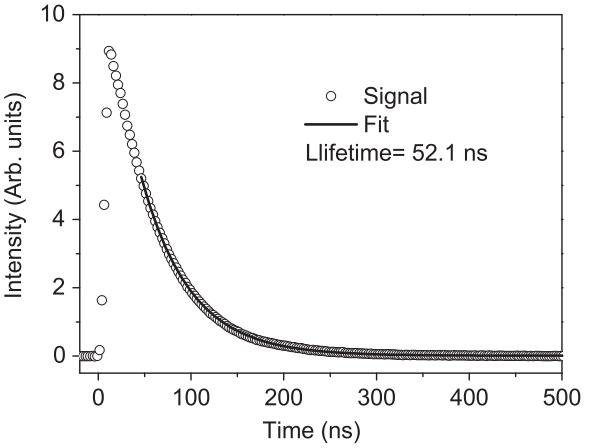

Fig. 2. Typical fluorescence decay curve of the 48,715.586 cm^{-1} level of Ni I with an exponential fitting.

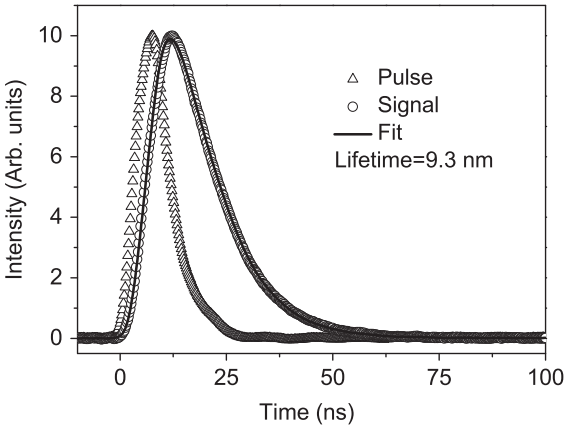

Fig. 3. Typical fluorescence decay curve of the 46,901.13 cm^{-1} level of Mn I with a convolution fitting.