Journal of the Optical Society of Korea, Vol. 4, No. 2, September 2000, pp. 75-78

Design of a High Temperature Oven for Measuring the Saturation Intensity of Samarium atom by using Two Wave Mixing

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(Received May 18, 2000)

We design a high temperature oven for measuring the saturation intensity of the transition line $4f^6 6s^2\ {}^7F_0 \leftrightarrow 4f^6 6s6p\ {}^1P(J=1)$ of the samarium atom. We first constructed a high temperature oven to generate the samarium vapor column and study the thermal characteristics of the oven. The oven is able to operate at a temperature up to about 1400 °C and the operation is tested by using several metals with high melting points. We describe two wave mixing experiment with the samarium vapor generated in the high temperature oven and obtain the saturation intensity by analyzing the first diffraction signal.

I. INTRODUCTION

Nonlinear optics is used for measuring the spectroscopic constants of materials [1], but, in the case of a gaseous medium, it sometimes needs a sufficient density of atomic gas to obtain a large signal, because the signal is generally dependent on the number of atoms. Materials with high melting points have not been studied with nonlinear optics. Atomic vapor has been generated by various methods such as hollow cathode discharge [2], resistance heating [3,4], electron beam heating [5,6] and so on. However, if the vapor-generator operates at high temperatures for generating dense atomic gas, the atomic source may soon become exhausted. We then must frequently load the sample into the vapor generator. Therefore, it is valuable to develop a device that is able to operate with a sufficient vapor density for a long time.

The development of this kind of device, such as a heat pipe oven, has been established for low melting point materials. The circulation of metal in the heat pipe oven allows it to operate for a long time. However, the conventional heat pipe oven should be used at low temperatures below several hundred Celsius due to surface oxidation. We must develop a device to operate at high temperatures and generate a vapor column that can be maintained for a long time.

In this paper, we present the design and the thermal characteristics of a heat oven that is able to operate at high temperatures, generate a vapor column, and lengthen the lifetime. The effect of ceramic tubes for reducing the radiation heat loss is discussed. A first wave mixing experiment on the generated samarium vapor in a high temperature oven is presented.

II. DESIGN OF THE TEMPERATURE OVEN

In general, a heat pipe oven operates under the temperature of about 800 °C due to the oxidation of its surface. The oven is evacuated by a mechanical pump

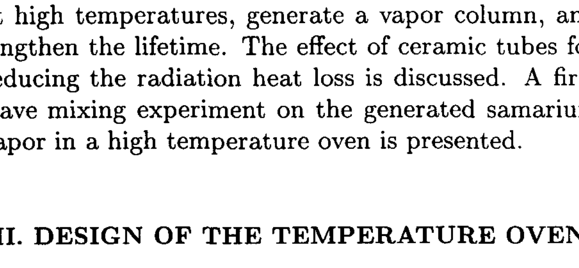


FIG. 1. The schematics of the heat oven.

TABLE 1. The specifications of the heat oven.

material	model	
ceramic tube	998 A (Vesurius) -99.8% Al_2O_3	≤ 1800 °C
ceramic bond	alumabond 484 (CERCOA)	≤ 1760 °C
thermocouple	R type (Pt-Rh20%/Pt-Rh40%)	≤ 1700 °C
	K type (Chromel-Alumel)	
tantalum wire	(Aldrich)	ϕ 0.5 mm
power supply	7475 A (Hewlett Packard)	120 V-18 A

to maintain a pressure of several hundred mTorr–Torr, so that the radiation loss dominates any other loss, such as conduction and convection loss. One method that overcomes this limitation is to use several cylindrical ceramic or metal plates which decrease the temperature on the outer surface by reducing heat transfer from the inner part to the outside. Therefore, we constructed a heat oven made of stainless steel with three ceramic layers inside the oven. The constructed high temperature oven is depicted in Fig. 1. It was composed of a main body and two four way crosses. The main body was made of stainless steel and wound with ceramic papers for thermal insulation. The cooling lines were wound near the flanges to cool it down to room temperature. The three ceramic tubes for the thermal insulation were then installed inside the main body. The innermost ceramic tube has a diameter of 10 mm and a length of 150 mm. We determined the length and the diameter sufficiently wide to be able to perform the wave mixing experiment such as a two or four wave mixing experiment. We used a tantalum internal heating wire with diameter about 0.5 mm and resistance about 1.6 ohm at room temperature. Two four-way-crosses were used for the laser windows, a thermo-couple, a vacuum pump and the electric feed through for supplying the electric power. The internal temperature was measured by an R-type thermo-couple (Pt-Rh 20%/Pt-Rh 40%, error is less than 1%) and an infrared thermometer (error is about 5%), simultaneously. The emissivity (e) of the ceramic surface was about 0.3 from the reference data book.

An external heating element was added for faster heating and obtaining higher temperatures and prolonging the lifetime of the internal heating wire. The specifications of the heat oven are shown in Table I.

III. CHARACTERISTICS OF THE HIGH TEMPERATURE OVEN

The temperature as a function of power consumption is shown in Fig. 2. The temperature difference between the innermost part and the environment was so large that a large amount of thermal energy can transfer to the environment through the outside stainless-steel wall. When increasing the temperature in the center, the radiation loss becomes more dominant than any other loss because the radiation loss is proportional to T^4. For obtaining higher temperature in the center, the power needed should be greatly increased. Fortunately, we can reduce the heat loss in the radial direction with an external heating element that keeps the surface at a fixed temperature of about 500 °C–800°C. The external heating device provided higher temperatures in the center as shown in Fig. 2 and, in addition, it helped to reach a stable temperature faster. According to the graph in Fig. 2, the operating temperature was measured to be less than 1400 °C. When an electric power of 866 W was supplied, the temperature reached about 1360 °C in the center.

After turning off the power supply, we measured the temperature as a function of time. The radiation loss and the conduction loss are proportional to T^4 and T, respectively. The radiation loss dominates the conduction loss at the high temperature. As temperature decreases, the conduction loss is more dominant than any other losses. We obtained decreasing rates of 44 °C/min at high temperature and 17 °C/min at low temperature.

In addition, the operation was tested with Gd, Er, and Sm elements. A gadolinium ingot was melted at

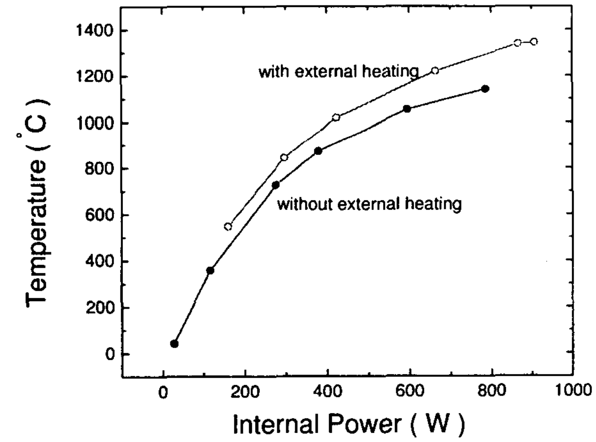


FIG. 2. The temperature in the center with respect to the supplied electric power. (a) without external heating, (b) with external heating

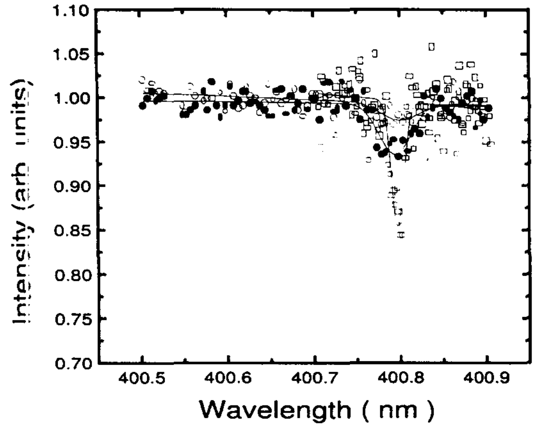


FIG. 3. The absorption profile in Er vapor. The white light is passing through the Er vapor and the transmittance at a wavelength around 400 nm is measured by the monochromator. The hollow circle, the solid circle, and the square are the data at a temperature of 1000 °C, 1080 °C, and 1150 °C, respectively.

around 1360 °C, because the vapor pressure of gadolinium is too low to observe absorption with a white light source and monochromator system. Erbium has a high vapor pressure even below the melting point (1529 °C), so we can observe the absorption spectrum at around 1100 °C. The considered transition line in the absorption experiment was $4f^{12}\ {}^3H_6 6s^2({}^1S_0)J = 6 \leftrightarrow 4f^{12}\ {}^3H_0 6s6p({}^1S_0)J = 7$ (400.8 nm). However, the absorption depth was measured only about 10% due to the radiation from the ceramic surface in the center.

We expected to obtain a sufficient density to perform an experiment, such as the saturated absorption experiment with erbium. For samarium, we could generate a high vapor density at about 800 °C–900 °C. We could observe the conical emission that can be observed in a high density vapor. In the next section, we describe the two wave mixing experiment in the samarium vapor that was generated in the high temperature oven.

IV. TWO WAVE MIXING EXPERIMENT

The two wave mixing experiment can be used for the remote measurement of density, the electric dipole moment, etc. When two pump beams are incident on the medium, a phase or population grating can be induced in the medium and several diffraction signals are generated near the pump beams. In a recent report, an analysis including complex physical phenomena has been established. We applied this experimental technique to measure the saturation intensity of the samarium atomic transition line, which is related to the electric dipole moment.

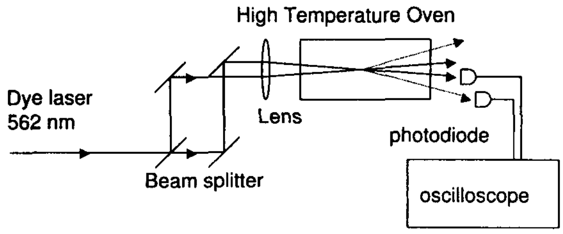


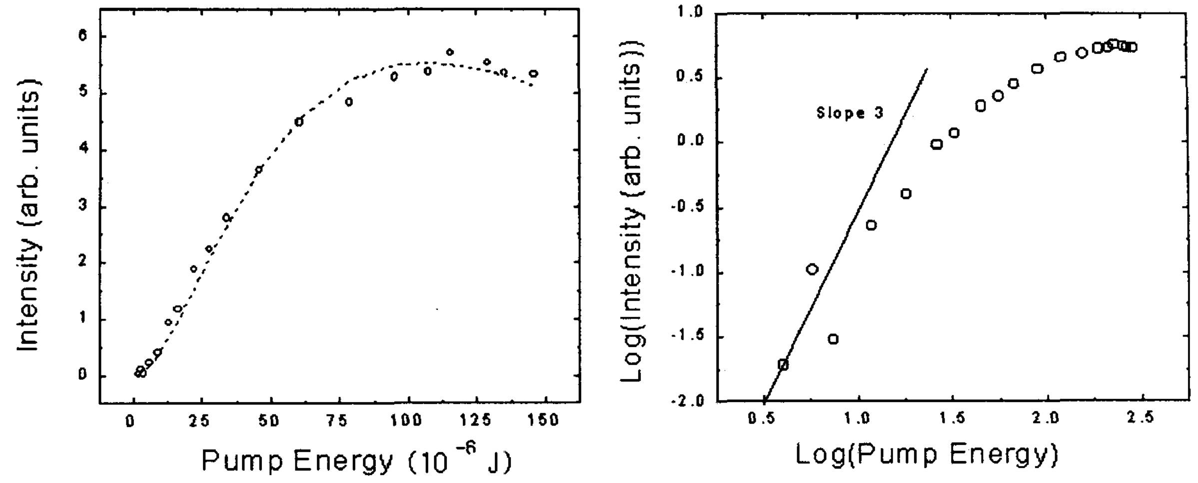
FIG. 4. Experimental setup of two wave mixing

The experimental setup for measuring the saturation intensity is depicted in Fig. 4. The wavelength of the dye laser, which was pumped by the second harmonics of the Nd:YAG laser, was tuned to the atomic line $4f^6 6s^2\ {}^7F_0 \leftrightarrow 4f^6 6s6p\ {}^1P(J = 1)$ (E=17769.71 cm^{-1}, λ =526.0 nm). The bandwidth and the pulse width of the laser light were about 3 GHz and 10 ns, respectively. The laser light was split into two beams by a beam splitter (50:50) and crossed again with a small angle in the oven center. The focal length of a lens was 1000 mm and the distance between the lens and the center of the heat oven was about 400 mm. The diameter of the laser beam in front of the beam splitter was controlled by an iris diaphragm and measured at about 2 mm, and the light energy was measured by a pyroelectric Joule meter. The first diffraction signal and pump energy were measured by a fast photodiode and a pyroelectric Joule meter, respectively. The signal intensity was too weak to measure the absolute intensity, so we could only measure the relative intensities with an arbitrary unit. The fast photodiode signal was averaged over every shot by a fast oscilloscope (TDS380:bandwidth 400 MHz) and saved in storage devices. The laser frequency was detuned to the blue side by 30 GHz to avoid the scattering problem in the on-resonant condition. Figure 5 shows the dependence of the first diffraction signal on the pump energy.

We used the equation in Q. Yang's paper [7] for the analysis of our data. The self phase modulation effect which slightly modifies the pump energy dependence was neglected to simplify the equation. We could observe the high orders of the diffraction signals (which are limited by the ceramic diameter) at a high pump intensity, but are strongly modified by the conical emission. We only considered the first diffraction signal ($I^{(1)}$) written as follows.

$$I^{(1)} = R^2 I_0 L^2 sinc^2(\frac{\pi L}{L_c})$$

$$R = \frac{k_0}{k_{1z}} \alpha_0 \sqrt{1 + \delta^2} I_0 I_s A^2 (1 - AI_0)$$



(a) (b)

FIG. 5. The first-diffraction signal with respect to the pump energy (continuous) and the fitted curve (dashed)(a); logarithmic plot of data (b).

$$\begin{aligned} L_c &= \frac{2\pi}{k_{0z} - k_{1z}} \\ \delta &= (\omega - \omega_0)T_2 \\ \alpha_0 &= \frac{\mu^2 N T_2 k_0}{2\epsilon_0 \hbar} \\ I_s &= \frac{\hbar^2}{T_1 T_2 \mu^2} \\ A &= \frac{1}{2I_0 + I_s(1+\delta^2)} \end{aligned} \tag{1}$$

where the δ is the detuning, T_1 is the lifetime of the excited state, μ is the electric dipole moment and N is the density of samarium gas. T_2 is the dephasing time to be equal to $1/\gamma$(γ is the dephasing rate). L, k, and I_0 are the interaction length, wave vector, and pump intensity, respectively. The subscripts 0 and 1 of k mean the pump and diffraction signal, respectively. The fitted curves using equation (1) are also shown in Fig. 5. We obtained the exponent of 3 in the low energy region in Fig. 5 because the total laser energy was controlled. In the results, when we choose $I_s(1+\delta^2)$ as a fitting parameter we obtain a value of 140(40) kW/m^2. We need to measure the dephasing rate (γ) and the laser bandwidth to obtain the spectroscopic constants such as the dipole moment from the above values.

V. SUMMARY

We described the design and thermal characteristics of a high temperature oven for nonlinear spectroscopy on metals with a high melting point, and performed wave mixing experiments on samarium vapor for the first time. We could obtain high temperatures by using three layers of ceramic tubes and external heating. We obtained temperatures up to about 1400 °C. We expect that this oven can be applied to several nonlinear experiments, such as saturated absorption spectroscopy and four wave mixing experiments, on high melting point materials.

REFERENCES

[1] H. Park, M.. Lee, E. C. Jung, J. Yi, Y. Rhee, and J. Lee, J. Opt. Soc. Am. B **16**, 1169 (1999).

[2] L. Jia, C. Jing, Z. Zhou and F. Lin, J. Opt. Soc. Am. B **10**, 2269 (1993).

[3] M. Szynarowska and R. Papaj, Physica Scripta **25**, 485 (1982).

[4] A. Nishimura, H. Ohba, K. Ogura and T. Shibata, Opt. Commun. **110**, 561 (1994).

[5] H. Niki *et al.*, Opt. Commun. **70**, 16 (1989).

[6] A. Dohnalik, T. Dohnalik and M. Szynarowska, Physica Scripta. **20**, 39 (1979).

[7] Q. Yang, J. Si, Y. Wang, and P. Ye, Phys. Rev. A **54**, 1702 (1996).