Bulgarian Journal of Physics 23 Nos 1/2 (1996) 73-78

AUTOMATED SYSTEM FOR TRANSIENT OPTICAL ABSORPTION MEASUREMENTS

I. RUSINOV, A. BLAGOEV
Faculty of Physics, University of Sofia
5 J. Bourchier Blvd, 1164 Sofia, Bulgaria

Received 25 March 1996

Abstract. An automated system based on 16 bit PC for time varying optical absorption measurements is described. The increased efficiency is due to the two channel monitoring of the photomultiplier signal. The evolution of ground state magnesium atoms density in a hollow cathode afterglow plasma is recorded.

1. Introduction

A large variety of transient processes connected with absorption or emission of light have characteristic times bigger than 0.1 μs. Usually such events are investigated by periodic pulse activation of the reacting media and monitoring of light emitted or absorbed in this media by means of optical spectroscopy. In these experiments there is no necessity to use the well-known method of multi-channel time analyses of the PM tube signal. By multi-channel analyses are measured the weak light fluxes in experiments where the excited levels lifetimes are determined. An essential condition for the application of this method is to ensure a high enough repetition rate of the experiment. This rate has to be substantially higher than the average frequency of the photon counts. Therefore if the characteristic time of the investigated process is several milliseconds (see for example the determination of the diffusion coefficient of Mg in He, T. Redko et al, 1993, [1]), then very low-level light flux has to be recorded reliably in order to obtain an adequate decay curve. In this case should be fulfilled quite severe requirements towards the electronic circuits and PM tube noises.

Additional difficulties could appear by the fact that the multi-channel registration of the absorption presumes a stable external light source with a continuous operation. Thus the conditions in the emission source and the absorption volume will not be similar. For example, in the afterglow of the low temperature, low density positive column (at pressure ~ 1 Torr), for correct absorption measurements quite important are the spectral lines profiles and the ratio between the emission and the absorption line widths. In the most convenient case the gas temperature in the emission source and

© 1996 St. Kliment Ohridski University Press All rights reserved

the absorption volume is the same, so the corresponding line profiles are identical. To achieve such a situation very low current (therefore low brightness) should be used in the emission source. When the temperatures in the emission and absorption volumes are different corresponding corrections should be introduced in the absorption density dependencies.

In a previous work of our laboratory an automated system for time varying optical absorption measurements [2] was described. An 8 bit processor was used as a system manager controlling experiment, data acquisition and processing. An improvement of time resolution of this device up to 100 ns was made in work [3]. However the system efficiency is not enough since it records the PM tube signal by one channel and is not able to perform more sophisticated processing of the empirical data in real time. In this work a new, more elaborated system is proposed. It is applied for measurements of the excited and normal atoms densities in the decay plasma of a Mg hollow cathode discharge.

2. General Part

The afterglow of a pulsed periodic gas discharge is medium suitable for investigation of many elementary processes between different atomic and molecular species. To measure the evolution of such species densities in the afterglow period, time resolved absorption experiment is needed. It means that the absorption of an external emission tube light flux in the investigated medium (absorbing tube) should be determined in narrow time gaps in the afterglow period. Gated photon counting is suitable technique for this purpose.

As it is well-known the relative absorption A_α of a spectral line is given by the expression:

$$A_\alpha = \frac{F_2 + F_1 - F_3 - F_0}{F_2 - F_0} . \tag{1}$$

A_α is the ratio of the four fluxes which have to be measured in such absorption experiments. They are: F_2 — the emission tube flux, $F_2 = \int_0^\infty f_0(\nu)\mathrm{d}\nu$; F_3 — the emission of both tubes working together; $F_3 = \int_0^\infty f_0(\nu)\exp[-\varkappa(\nu)l]\mathrm{d}\nu + F_1$; F_1 — the absorbing tube self-emission; F_0 — the background. $f_0(\nu)\mathrm{d}\nu$ is the spectral flux density of the line emitted by the source tube, l is the absorption volume length, $\varkappa(\nu)$ is the spectral absorption coefficient.

If the self-emission of the absorbing medium is negligible then it can be assumed that $F_1 \approx F_0$ and one measurement can be omitted. The time diagram showing the corresponding control pulses is represented in Fig. 1*a*.

The absorption and the emission tubes are operated in a pulse periodic mode (pulses I_1 and I_2) and are switched on or off in four combinations to allow measurement of the mentioned four fluxes. Pulse I_3 is an internal gate that enables photon counting. Each of these combinations is kept for a period of time named acquisition period (1–100 s or even more) to allow piling up of enough counts in order to achieve the appropriate signal-to-noise ratio.

This setup will have a serious drawback if the emission flux has a great time drift, or the essential absorption and emission tube parameters (temperature for instance) change significantly during the acquisition time needed to measure the separate fluxes. An improvement introduced in this work is shown in Fig. 1*b*. It is valid in the afterglow investigations where the late afterglow of the absorption tube is characterized with negligible self-emission and zero absorption (absorbing species density is below the detection limit). This requirement is important and should be validated before measurement.

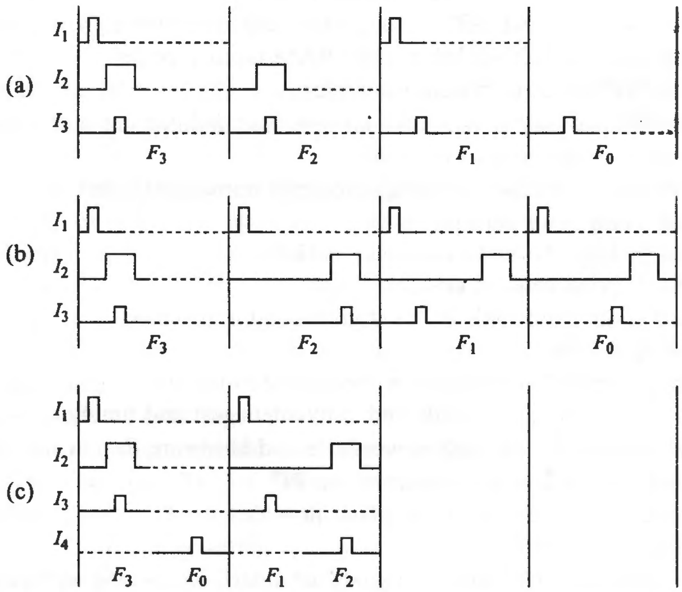

Fig. 1. Time diagrams of the pulses controlling the experimental setup (a) one-channel four cycle acquisition scheme, (b) one-channel four cycle acquisition scheme with a continuous operation of the pulse discharge tubes, (c) two-channel two cycle acquisition scheme

The advantage of this setup is that both tubes are operated in continuous pulsed mode which provides stable temperature during all measurement phases. If all phases of measurement alternate continuously in time during the acquisition period with a frequency giving a characteristic time less than the characteristic time of a possible drift, then the fluxes are measured in a quasi-simultaneous mode which is advantageous.

The next step substantially improving the efficiency of the device also is based on the quasi-simultaneous mode discussed above. It is a two-channel system which allows to speed up the measurements twice. Its measurement scheme is shown in Fig. 1*c*.

The two pulses I_3 and I_4 gate two separate counters which pile up counts from the photon counting system at two programmed delays in the afterglow. During the first phase the fluxes F_3 and F_0 are measured "together" and during the second — F_1 and F_2.

3. System Description

The hardware unit for pulsed discharge afterglow absorption measurements is based on the modular automated system designed especially to fulfill our experimental needs. The idea is based on the experience with optical and Langmuir probe measurements in pulsed gas discharges conducted in our lab. However it is flexible enough to be employed in other setups.

The system consists of two main parts: a computer and crate (or several crates — EUROCRATE standard) with a separate power supply and plug-in modules. The computer may be a PC XT/AT, connected to the crate through the interface. Our prototype employs a 386SX 40 MHz 2 Mb RAM mother board.

General view of the crate system principles:

1. Expandable and easy-to-use modular interface architecture with logical addressing of modules (slots are identical).
2. Versatile high and low-level language programming of interface.
3. Powerful computing abilities.
4. Reasonably large I/O address space (64KB).
5. Rich interruption request system.
6. Standard connection with PC on a considerable distance.
7. Upgrading abilities.
8. Low-digital noise interference in the analog circuitry.
9. Easy access to module boards and convenient test and tuning.

These principles make the system versatile and hardware design time saving.

Two printed circuit boards — one in the PC XT/AT, mother board I/O slot and other — connected to the crate back plane provides the PC-crate interface through a 40-wires flat cable.

To ensure a correct I/O with a variety of interfaces having different speed, the request — wait mode of PC input and output is modified to a type of default — wait one. It is a time-limited asynchronous mode in which the processor includes up to 10 wait clock periods in its I/O cycle, waiting to get a ready signal from the peripheral equipment.

The crate system provides a 8-bit data BUS, 16-bit address BUS, 8-levels of interruption request and several control signals. It has its local power supply unit for digital (+5 V) and analog (±20 V) modules circuitry, separate digital and analog grounding. The crate memory address space is 64KB and is organized in 1024 pages, 64 bits each. All peripheral modules are connected to the crate back plane by a 64-pin connector (EUROSTANDARD). They have jumpers which determine the local address space allocation throughout the crate address space. Fifteen crate BUS lines are left free for future expansion (i. e. 16-bit data BUS) and digital and analog interconnections between peripheral modules.

The processing of interruption request is organized on the base of one Intel 8259 chip. The INT output line of the chip is wired to the IRQ2 (IRQ9 for AT) pin of PC I/O channel.

All interrupt requests from the crate are active low, and on each IRQ line one can attach many requests by wired OR. The crate I/O signals are -CrRD:read, -CrWR:write and -CrSel:select crate interface (active low).

They can be locked to a high level by a computer command, which decreases digital noise in some sensitive analog measurements.

Generator-counter module

This module provides 4 synchronized TTL pulse channels with a computer controlled period and duration of output pulses: I_1, I_2, I_3, I_4 and also an independent computer controlled delay of each one of the pulses I_2, I_3 and I_4 with regard to the rising edge of pulse I_1. The best time resolution of I_1, I_2 and I_3 is $0.6\,\mu$s and of I_4 is about $80\,\mu$s which can be decreased further. Channel I_4 can be switched between two modes of operation: microsecond and nanosecond. The pulse repetition frequency range is: 25 Hz–1.7 MHz.

The counter section of the board consists of two 21 bit counters that can be internally (pulses I_3 and I_4) or externally gated and an acquisition time interval timer, internally or externally clocked. The ability of external synchronization makes the module versatile to fit various optical and other experiments and also to be used as a part of an ADC (U/F converter) with powerful noise suppression abilities.

The board can be programmed to send an interrupt request signal after a given acquisition time interval has elapsed or, this option could be disabled driving the system in an ungated mode of counting.

The board uses 4 programmable interval timers INTEL 8253 which are programmed through the crate interface by the system computer and has local 14 MHz quartz stabilized oscillator.

Employing two-photon counting channels the optical absorption registration scheme becomes twice faster than the traditional single-channel one in plasma afterglow time resolved measurements.

Of course it is interesting to try a multi-channel system, that could be able to measure the whole afterglow period at a time. This will give a dramatically new level of system productivity, eliminating the problems connected with long-term absorption tube parameters change. The electronics required is not sophisticated, but this approach, however, requires a very special emission source. Usually we use a pulsed light source that gives considerable brightness in the pulse at small average currents. If the choice is a pulsed source, then the pulse duration should be big enough and easily changeable (preserving its stability) to fit different experimental conditions. In the pulsed hollow cathode discharge lamps, however, an essential change in the emission line brightness and (conneected with the light reabsorbtion) takes place along the discharge pulse due to the continuous change of the sputtered atoms density in the volume. This phenomenon will cause distortion in the measured afterglow absorption curve, because different channels will operate on an emission base that gives different brightness and line profile.

Instead of a pulsed light source, a continuous discharge spectral lamp could be used with stable emission and temperature. However the small brightness and line broadening problems of such a source should be thoroughly considered. The intrinsic noise of the whole experimental scheme should be as low as possible.

In spite of the difficulties mentioned, a further development of a multi-channel system is doubtlessly an attractive task.

4. Experimental Results

An illustration of this type of measurements is shown in Fig. 2. The curve presents the afterglow period evolution of the density of Mg atoms sputtered from the walls during the active discharge phase in a magnesium hollow cathode glow discharge. The diameter of the cylindrical hollow cathode is 1.9 mm and its length — 12 cm. The carrier gas is neon at 1 Torr pressure. The main reason for the decrease of the atom density is the diffusion towards the walls. Using the measured decay rate, the corresponding diffusion coefficient can be obtained.

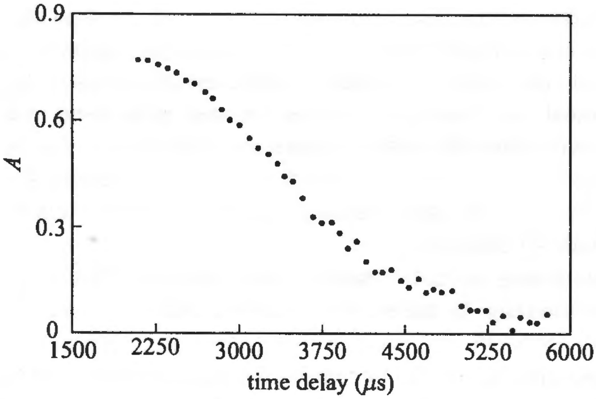

Fig. 2. The evolution of the ground state Mg atoms relative absorption recorded in the afterglow of Mg–Ne negative glow. Pulse current 100 mA Ne pressure 1 Torr

Asknowledgements

This work was supported by the Sofia University Science Fund, project 152/1995 and the Bulgaria National Research Fund, project F579/95.

References

1. T. Redko, I. M. Rusinov, A. B. Blagoev. *Journ. of Phys. B, At. Mol. and Opt.* **26** (1993) 107.
2. G. Koinakov, N. Pilosof, A. Blagoev. *Spectroscopy Letters* **19** (1986) 1113.
3. N. Pilosof, A. Blagoev, G. Koinakov. *Bulg. Journ. of Phys.* **15** (1988) 302.