Hz. At this frequency the channel dwell time for a 1024 channel spectrum (plus the mirror) works out to be 48.83 μsec. The updating of each channel in the above process takes a maximum of 800 ns. Thus the dead time per channel is minimized. Signals to X and Y channels of the oscilloscope are obtained from 16-bit digital-to-analog converters (DACs). Digital inputs to DACs are the address of the MSRAM and most significant word of the count stored in the MSRAM.

At the beginning of the experiment, the reset button is pressed. This makes one of the inputs of the AND gates to logic "*O*" and clears the multiscaler RAM. Data acquisition is started by pressing the start button. After obtaining required intensity of the spectrum, the data acquisition is stopped and acquired data is logged into the microcomputer via 8255. Each channel occupies three successive memory locations of the microcomputer memory. The spectra obtained for up and down ramps are then combined, by carefully overlapping them until they match exactly. The final spectrum is stored on a floppy disk for further analysis. The multiscaler RAM is battery backed-up so that a possible power failure will not disturb the memory contents.

The multiscaler constructed by us is in routine use and working excellently.

[1] A. Biran, A. Shoshani, and P. A. Montano, Nucl. Instrum. Methods **89**, 21 (1970).
[2] M. J. Graham, D. F. Mitchell, and J. R. Phillips, Nucl. Instrum. Methods **141**, 131 (1977).
[3] M. A. Player and F. W. D. Woodhams, J. Phys. E **11**, 191 (1978).
[4] P. E. Holbourn, M. A. Player, and F. W. D. Woodhams, Nucl. Instrum. Methods **165**, 119 (1979).
[5] H. Th. Le Fever, Nucl. Instrum. Methods **166**, 133 (1979).
[6] J. Linares and J. Sundqvist, J. Phys. E **17**, 350 (1984).
[7] E. Wallingford and C. Bordeleau, Rev. Sci. Instrum. **56**, 1253 (1985).
[8] K. Raghavendra Rao, Ph.D. Thesis, Sri Krishnadevaraya University, Anantapur, India, 1986.

Picosecond laser timing by rf phase shifting

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Generation of picosecond and nanosecond time-scale time delays in a pump-probe laser system has been implemented without the use of an optical delay line, by rf-phase shifting of the mode-locking rf-signal. The system consists of dual picosecond dye lasers pumped by synchronized mode-locked, *Q*-switched, cw Nd:YAG lasers. The phase shifter operates with better than 10-ps precision and generates time delays from 0 to 26 ns.

Picosecond pump-probe laser experiments have proved to be a powerful means of studying ultrafast phenomena in a wide variety of physical, chemical, and biological systems.[1] In a typical experiment, the sample is excited with a pump pulse, and probed after a variable time delay by a probe pulse. Time delays on the picosecond and nanosecond time scales are usually generated by an optical delay line consisting of a prism on a stage that is translated to vary the path length of the probe beam. Unfortunately, in such experiments, errors in the measured time dependence of the probe signal may result from slight misalignments of the delay line, or from the dependence of the probe beam parameters (beam diameter and radius of curvature) on propagation distance.

Recently, we reported a laser system with the capability of performing pump-probe experiments with time delays from the picosecond to the millisecond time regimes with ~50-ps time resolution.[2] Time-delays of tens of nanoseconds or greater are generated as integral multiples of the round-trip time of the laser (13 ns) by a timer clocked at the mode-locker frequency (76 MHz). However, time delays of less than 13 ns were generated by an optical delay line and therefore, subject to the disadvantages described above.

In this note, we report generation of time delays on the picosecond and nanosecond time scales by phase shifting one of the mode-locked Nd:YAG lasers. (An initial test of this technique was reported previously.[3]) This method circumvents the use of an optical delay line and its attending disadvantages. The laser system has been described in detail elsewhere.[3] In brief, two mode-locked, *Q*-switched, cw Nd:YAG lasers (Quantronix 116) synchronously pump two cavity-dumped dye lasers. Both Nd:YAG lasers are mode-locked by the same rf source and therefore generate well-synchronized pulse trains. Timing jitter between cavity dumped pulses from the two dye lasers was determined to be ~50 ps. Figure 1 shows a schematic of the laser system.

The previously described system has been modified as follows (see Fig. 1). A voltage-controlled phase shifter (Merrimac Industries PME-4/59194) was inserted between the rf source and the rf amplifier (ENI 325LA) driving the acousto-optic mode-locker of one Nd:YAG laser. The phase

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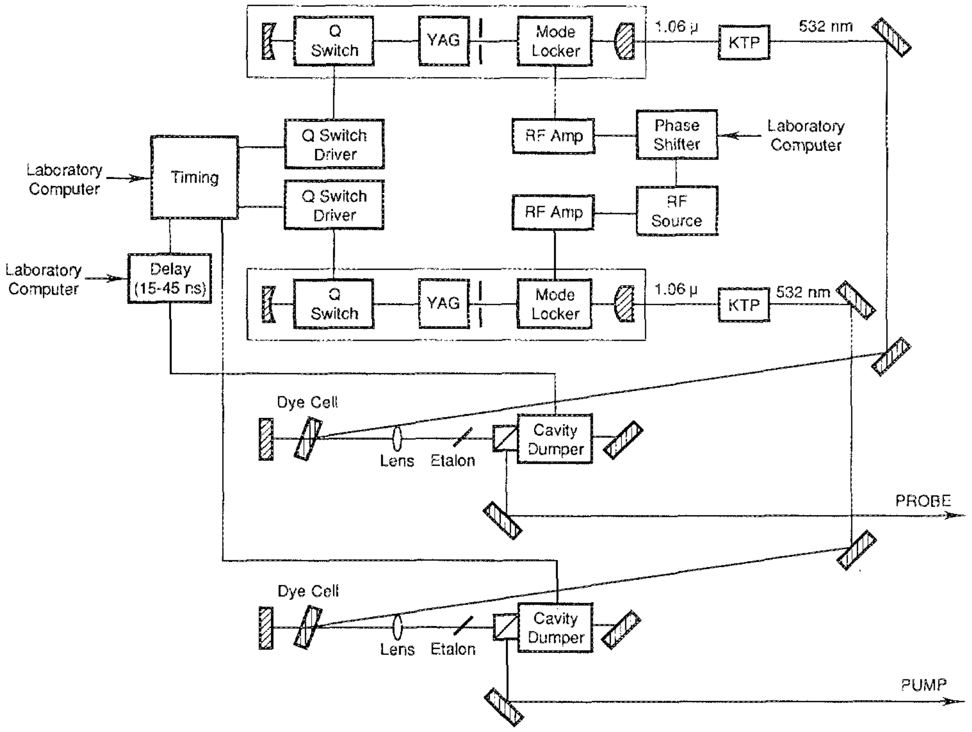

FIG. 1. Picosecond pump-probe laser system with phase shifter to generate picosecond and nanosecond time delays. KTP = $KTiOPO_4$.

shift is monotonic as a function of control voltage, and variable by more than one period of the 38 MHz mode-locking signal. This phase shift generates time delays in our system of more than 26 ns. The calibration curve is shown in Fig. 2. The phase-shift time delays were measured by second harmonic cross-correlation.[4]

Time delays and time scans are controlled by the laboratory computer via a 12-bit digital-to-analog converter. A cubic splines interpolation is used to determine the control voltage necessary to generate the desired phase shift. As the phase shift is varied by scanning the control voltage, the pulse train from the phase-shifted Nd:YAG laser shifts smoothly with respect to the pulse train from the unshifted Nd:YAG laser. The synchronously pumped dye-laser pulses follow the shifted Nd:YAG pulses. The cavity dumpers are triggered by a master timing circuit, which generates time

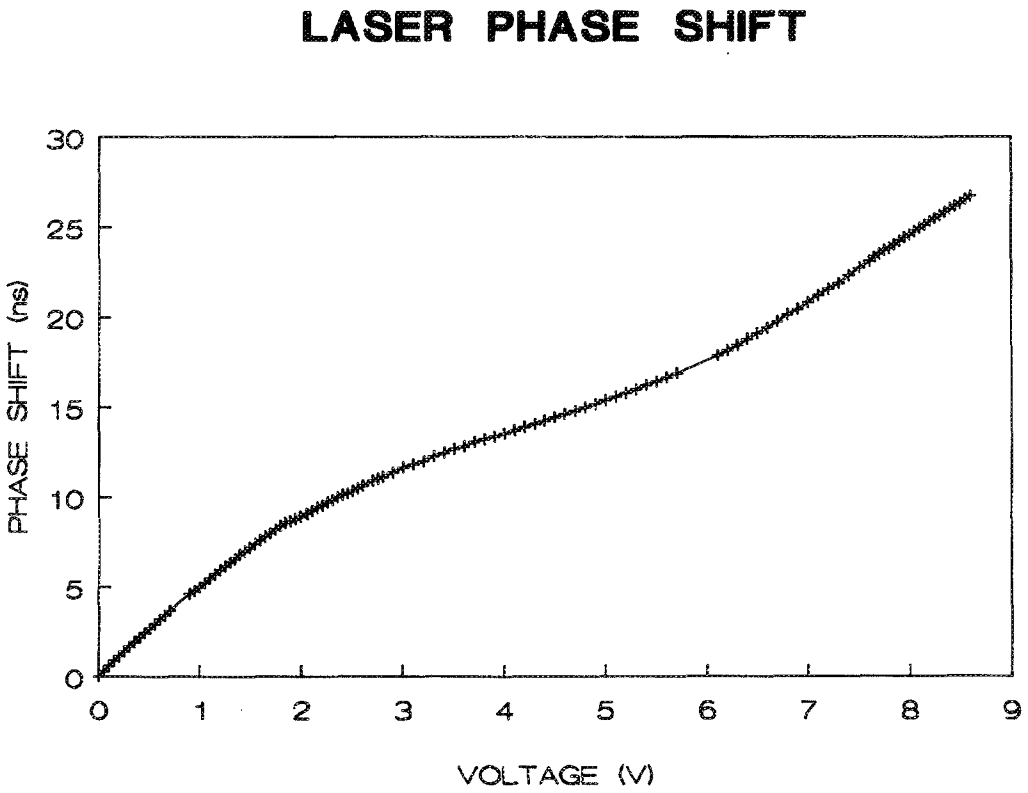

FIG. 2. Phase shift time delay as a function of control voltage. Crosses are measured delays. The solid line is a cubic splines interpolation.

delays between pump and probe pulses in units of 13 ns.[2] As the time delay is scanned by phase shifting, it is necessary simultaneously to adjust the timing of the cavity-dump trigger pulse to follow the scanning dye-laser pulse train in a course-grained fashion, in order that the delayed probe pulse is selected cleanly by the cavity dumper. A 4-bit programmable delay line (Engineered Components Company PTTLDL-15-2) is employed to delay the probe laser cavity-dump trigger by 15–45 ns in units of 2 ns, tracking the shifted dye-laser pulse selected by the cavity dumper. The variable delay in the cavity-dump trigger signal for the probe laser is controlled simultaneously with the phase shift by the laboratory computer.

In summary, we have described a method of generating picosecond to nanosecond time-delays in picosecond time-resolved pump-probe dye-laser experiments, without the use of an optical delay line. Computer controlled time delays are readily obtained in our laser system with 10-ps resolution over time scales from picoseconds to milliseconds without the use of an optical delay line. Thus, laser alignment and beam properties are unaffected by time delay over this entire delay range.

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[1] Graham R. Fleming, *Chemical Applications of Ultrafast Spectroscopy*, (Oxford University Press, New York, 1986), Chap. 4.

[2] C. K. Johnson, J. M. Bostick, S. A. Mounter, K. L. Ratzlaff, and D. E. Schloemer, Rev. Sci. Instrum. **59**, 2375 (1988).

[3] J. M. Bostick, S. A. Mounter, and C. K. Johnson, Opt. Commun. **69**, 54 (1988).

[4] E.P. Ippen and C.V. Shank, in *Ultrashort Light Pulses*, 2nd ed., edited by S. L. Shapiro (Springer, Berlin, Heidelberg, 1984), pp. 90–92.

Gain of a secondary electron multiplier with ring-shaped continuous dynodes in a magnetic field

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The gain of a secondary electron multiplier has been measured in the magnetic field perpendicular to ring-shaped continuous dynodes. It has the maximum value at the magnetic flux density of about 80 G.

Detection of charged particles and photons in a magnetic field are important in many areas of research such as plasma physics. The gain of a secondary electron multiplier with separated dynodes decreases rapidly in the magnetic field generally. On the other hand, for a multiplier with continuous dynodes such as a channeltron, the influence of the magnetic field upon the gain is weak.[1,2] It was reported that the gain of a channeltron with a circle arc pipe dynode increased slightly in the curved magnetic field along the pipe.[3]

In a previous work, the author developed a secondary electron multiplier with separated ring-shaped dynodes[4] and one with continuous ring-shaped dynodes.[5] In this note, influences upon the gain of the latter multiplier have been measured in a magnetic field perpendicular to the dynodes.

Figure 1 shows a schematic figure of this electron multiplier and its electron orbits with no field (solid lines) and with a field (dashed lines). The dynode made from ceramic is a ring-shaped plate with an inner diameter of 20 mm, an outer diameter of 70 mm and a thickness of 2 mm. Two circular dynodes were placed at a separation of 0.5 mm. A layer of Ge and one of Al_2O_3 were made by using an evaporation method on a dynode. Details of the structure of the multiplier were mentioned in the previous paper.[5] Electrons from a tungsten filament were accelerated up to the energy of 300 eV, and entered into the multiplier. Electron currents emitted from the filament and output currents multiplied at two dynodes were measured by a picoammeter (Keithley 485), a nanoammeter (Yokogawa 2707) and a microammeter (Yokogawa 2011). The magnetic field made electrically by a coil with 1000 turns was applied perpendicular to

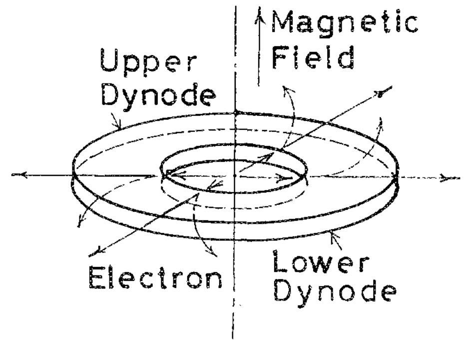

FIG. 1. Schematic figure of the constructed electron multiplier with electron orbits (solid lines) and with those in the magnetic field (dashed lines). The figure is not to scale.