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Automation of a popular monochromator

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A wavelength-scan and intensity-control system for a widely-used, high-intensity monochromator is described. The wavelength scan is bidirectional and variable speed, and may be controlled manually or by TTL logic from a computer. The intensity control is effected by use of a programmable dc power supply and D-A converter. Various filters are described which allow an intensity of up to 2×10^{14} photons/cm² s to be achieved in a 1 cm $\times$ 3 cm area over a wavelength range 0.76–2.50 μ m, at 0.07 μ m bandwidth, with a single grating. (A lesser intensity is available to 3.4 μ m.) This wide range is made possible by the use of second-order light from 0.76–1.00 μ m. Photoconductivity data in GaAs:Cr and InP:Fe are presented, as an example.

PACS numbers: 07.60. — j

INTRODUCTION

A popular monochromator presently used in many laboratories throughout the world is the Bausch and Lomb (B&L) High Intensity Monochromator. This instrument is small (1/4 m), relatively low cost, and has f/3.5 optics. Various options and accessories include a choice of three light sources (tungsten-halide, mercury, or deuterium), five gratings (ranging from 0.2 to 3.2 μ m), variable entrance and exit slits, and an adjustable achromatic lens. Unfortunately, however, the only wavelength scanning unit designed for the instrument is a relatively primitive, one speed (1 rpm), unidirectional, synchronous motor drive, which is insufficient for many applications. It would be more desirable to have bidirectional capability, variable speed, a wavelength readout, limit switches to avoid overdriving the grating screw, and external-drive capability to allow computer control. Since we found nothing on the commercial market which satisfied these criteria it was necessary to design our own unit, which is the main subject of this paper. It is also desirable to maintain constant intensity during the wavelength scan, and this problem was solved by using a programmable dc power supply on the tungsten light source. Finally, we have identified the various filters necessary to obtain a minimum intensity of 2×10^{14} photons cm⁻² s⁻¹ (in an area of 3 cm²) over the wavelength range 0.76 to 2.50 μ m, by using a single grating (the B&L 1.4–3.2 μ m grating). In fact, wavelengths up to 3.4 μ m may be obtained from this grating, with somewhat reduced intensity, of course. Note that this wavelength range is useful for investigating the photoelectronic properties of impurities in many important semiconductors, including Si, Ge, GaAs, and InP.

I. APPARATUS

A. Grating drive

The mechanical part of the grating drive mechanism consists of a stepping motor, position potentiometer,

and associated gearing, as shown schematically in Fig. 1. These components are mounted in a small box (5 1/2 $\times$ 3 1/2 $\times$ 3 1/2 in.) which bolts into two existing threaded holes in any of the B&L High Intensity grating assemblies. The coupling to the grating screw shaft is positive and backlash is minimal. (Reproducibility will be discussed later.)

The electronic circuitry is shown in Fig. 2. Here we have incorporated a power supply and translator module produced by the motor manufacturer. (All the component types, model numbers, and manufacturers are listed in Table I.) For automated operation the necessary inputs include a TTL logic level, for motor direction, and TTL pulses, to drive the motor. The primary output is a voltage derived from the position potentiometer which corresponds to the motor position. The upper and lower wavelength limits are set by front-panel potentiometers, and LED's indicate when one of the respective limits is reached. The voltages (indicated by "5P" in Fig. 2) for the limit and position potentiometers are derived from a separate regulator. Front panel controls include, besides the limit potentiometers, an auto-internal-jog switch, a direction switch (for internal run and jog modes), and a speed control, for internal-run operation. In addition, there is a jog momentary switch,

FIG. 1. An isometric view of the mechanical components. The potentiometer is designated "P" in Fig. 3, and the stepping motor "M". The size of each plate is 3 1/2 $\times$ 5 1/4 in.

FIG. 2. A circuit diagram of the Grating-Drive Control Unit (cf. Fig. 3). The circled letters are terminal designations on a Slo-syn STM101 Translator Module. The hexagonally-enclosed numbers are remote connections, as follows: No. 1: from computer-controlled source of TTL stepping pulses; No. 2: from computer-controlled source of TTL "Hi" or "Lo" voltages, corresponding to cw or ccw motor directions, respectively; No. 5: to A-D converter, and then to computer. Here the designation "wavelength," at No. 5, is of course really the position-potentiometer voltage, which is subsequently converted by the computer to a wavelength. The dotted line between the position potentiometer and the stepping motor denotes a coupling between their respective motions. The upper and lower limits of the motion are set by the 5 K potentiometers in the limit circuits. A separate regulator ("317") supplies the voltage ("5P") for these circuits.

which turns the motor a single step if the auto-internal-jog switch is in the jog position. In summary, then, the grating drive may be jogged in single steps, run continuously at a speed and direction determined by front-panel controls, or run automatically, with speed, direction, and rotational distance determined externally.

B. Intensity control

Spectroscopy experiments are most easily interpreted if the light intensity is constant over the wavelength range of interest. Often this problem is either ignored or is dealt with later by attempting normalization to grating, source, and filter envelopes. The latter procedure will be correct only if the particular response being studied is either linear with intensity over the whole range, or else at least follows some known relationship.

The two obvious ways to vary intensity are: (1) vary the entrance slit width, or (2) vary the source intensity itself. Method 1 is quite inconvenient on this particular monochromator because the slit width is not controlled by a vernier micrometer screw, which then would be easily amenable to a motor drive. Also, in any case, method 1 would have the disadvantage of a slower response than method 2. In adopting method 2 we chose to use dc power, although the B&L tungsten-halide lamp normally operates on 6.8 V ac, stepped down from the 110 V line voltage. Accordingly, the lamp circuitry was slightly

modified, so that either the normal ac power or external dc power could be used. A programmable dc power supply, with ratings 0-8 V and 0-8 A, is used in these experiments.

C. System control

The complete automated system is shown in Fig. 3, with the component types and manufacturers specified in Table I. To set the intensity, an integer (0-999) from the computer is converted to a control voltage (0-10 V) at the D-A converter, and is subsequently converted to a voltage (0-10 V) at the lamp power supply. The precision is 0.1%. To set the wavelength, the computer first converts the desired wavelength to an equivalent position-potentiometer voltage, according to a predetermined relationship. The computer then turns the stepping motor, by means of the stepping motor pulser board, until the instantaneous voltage at the potentiometer equals the desired voltage (wavelength).

II. CALIBRATION AND PERFORMANCE

A. Wavelength

Because of the rigid coupling between the motor, grating screw, and potentiometer, each voltage V_λ derived from the potentiometer represents a unique grating position, or wavelength λ . In fact, the relationship between λ and V_λ over the relevant wavelength

TABLE I. Equipment identification for the various items shown in Fig. 3. (Abbreviations: B&L = Bausch and Lomb, K = Keithley, DEC = Digital Equipment Corp.)

Designation	Mfg. Type and Model No.
Lamp Source	¹ B&L Tungsten Halide Source (33-86-39-01)
Monochromator	B&L High-Intensity Monoc., 1.4–3.2 μm Grating (Housing: 33-86-25, Grating: 33-86-78)
Lens	B&L Achromatic Condenser Lens (33-86-53)
Lamp PS	² Kepeco JQE 15-12M Programmable Power Supply
D-A Conv.	Kepeco SNR 488-4 Mainframe with SN488D Programming Card
Grating Drive Control	Fig. 2—includes ³ Slo-syn MPS1000 Power Supply and STM101 Translator Module
P	⁴ Beckman 7603 10K Potentiometer
M	Slo-syn MO61-FC08 Stepping Motor
Stepping Motor Board	⁵ K7901 Stepping Motor Interface Board in K790 Mainframe
A-D Conv.	K172 Digital Multimeter with K1723 Interface
Computer	⁶ DEC PDP 11-03 (with IEEE-488 I/O bus).

¹ Bausch & Lomb, 820 Linden Av., Rochester, NY 14625

² Kepeco, 131-38 Stanford Av., Flushing, NY 11352

³ Superior Electric Co., 383 Middle St., Bristol, CN 06010

⁴ Beckman Instr., 2500 Harbor Blvd., Fullerton, CA 92634

⁵ Keithley Instr., Inc., 28775 Aurora Rd., Cleveland, OH 44139

⁶ Digital Equip. Corp., 146 Main St., Maynard, MA 01754

range is nearly linear, although a better fit is given by the following third-order polynomial (for the 1.4–3.2 μm grating): $\lambda = -0.0524 + 0.670 V_{\lambda} + 0.0128 V_{\lambda}^2 - 0.00142 V_{\lambda}^3$. Here V_{λ} ranges from 1.5–3.7 V as λ ranges from 1.0–2.5

FIG. 3. A block diagram of the automated system. Manufacturers and model numbers are identified in Table I. Peripheral equipment items, such as the plotter (H-P 9872A), are not shown, for clarity.

TABLE II. Filters used with the B&L 1.4–3.2 μm grating.

Filter	Wavelength range	Grating range	Light order
¹ Corning 7-69	0.76–1.00 μm	1.52–2.00 μm	second
Corning 7-56	1.02–1.06 μm	1.02–1.06 μm	first
² Si	1.08–1.80 μm	1.08–1.80 μm	first
² Ge	1.82–3.40 μm	1.82–3.40 μm	first

¹ Corning Glass Works, Corning, NY 14830

² Adolf Meller Co., P.O. Box 6001, Providence, RI 02904

μm . Each experimental calibration point over this range is within 0.0005 μm of the above fit. More importantly, however, any value given to the computer is reproduced at the grating to within 0.001 μm , generally, and always to within 0.002 μm , even after remounting the unit. This precision is totally sufficient for most applications, especially since the bandpass of the 1.4–3.2 μm grating is itself normally much larger (about 0.025 μm at a 1 mm exit-slit width). The reproducibility described here confirms the mechanical and electronic integrity of the various components.

B. Intensity

The relationship between light intensity and wavelength is determined by the various envelopes due to source, grating, and filters. Accordingly, it is complex and highly nonlinear, precluding a simple polynomial fit such as that described in the previous section. Instead

FIG. 4. Some representative ac and dc photoconductivity data obtained by using the system described in this report.

we have made up a data file, on a magnetic floppy disk, consisting of an integer (0–999) for each wavelength in the range 0.76–2.50 μm , in 0.02 μm steps. These integers are chosen such that a constant intensity of 2×10^{14} photons $\text{cm}^{-2} \text{s}^{-1}$ is maintained in a 1 cm $\times$ 3 cm rectangular pattern. Here we are using the 1.4–3.2 μm grating (337.5 lines per mm, 2.0 μm blaze wavelength), tungsten-halide light source, achromatic lens, 6 mm entrance slit, and 3 mm exit slit. (The calibration detector was a Hewlett-Packard Mod. 8334A thermopile used with an H-P 8330A Radiant Flux Meter.) The calibration described above is maintained to within 3% over a period of several months.

The various filters used, along with their concomitant wavelength ranges, are given in Table II. The ability to achieve intense light at 0.76 μm , with a grating *intended* for the 1.4–3.2 μm spectral range, is made possible by the unique properties of the Corning 7–69 filter, which has less than 0.1% transmittance from 1.1 to 2.2 μm , but greater than 35% transmittance from 0.76 to 1.0 μm . Thus, with this filter in place, a grating setting of 1.80 μm (first order), for example, will produce almost no 1.80 μm light, but strong 0.90 μm light, in second order. This feature is quite important for semiconductors such as GaAs and InP, because it is then possible to obtain above-bandgap energies without changing gratings. Note from Table I that the 1.4–3.2 μm grating can actually be extended to 3.4 μm , which is near both the end of the grating drive range and the point at which the Ge filter begins passing second-order light. The intensity from 2.5–3.4 μm is of course reduced from the normal

2×10^{14} photons $\text{cm}^{-2} \text{s}^{-1}$. Another problem in this wavelength range is that a strong atmospheric absorption band appears between about 2.7 and 2.9 μm . In spite of these problems good data may still be achieved in this range, with proper corrections.

III. DATA

In Fig. 4 we present photoconductivity data from a GaAs:Cr sample (dc measurements) and an InP:Fe sample (ac measurements). The GaAs:Cr was p type, with dark conductivities of 9.2×10^{-3} and $1.3 \times 10^{-7} \Omega^{-1} \text{cm}^{-1}$ at 296 and 159 K, respectively. The InP:Fe was semi-insulating, with a dark conductivity of $6.8 \times 10^{-8} \Omega^{-1} \text{cm}^{-1}$ at 296 K. The dc conductivity measurements (GaAs:Cr) are in absolute units ($\Omega^{-1} \text{cm}^{-1}$) while the ac measurements (InP:Fe) are in arbitrary units. The filters used in the various wavelength ranges are also shown in the figure. Data acquisition, calculations, and plotting were all carried out without operator assistance, except for filter changes. (In our system, the computer activates a buzzer when it is time for a filter change.) The time delay between successive data points may be varied.

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