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INVESTIGATION OF THE PULSE OPERATION WAVELENGTH CHARACTERISTICS OF INFRARED EMITTING DIODES

BY

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B.E.E., Pratt Institute, 1963

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
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1976

ACKNOWLEDGMENT

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CHAPTER 1

INTRODUCTION

1.1 Objectives

The primary objective of this report is to present the findings of the investigation of the pulse operation wavelength characteristics of infrared emitting diodes at room temperature. The area of interest is the change in peak emission wavelength caused by the temperature rise of the diode junction during the application of a current pulse. Major emphasis will be placed on the use of transient thermal resistance of an infrared emitting diode to enable the prediction of emission wavelength change. The secondary objective is to present information in the area of semiconductor light emission.

1.2 Procedures

The first step is to investigate literature to obtain background information in the area of semiconductor light emission. General information in this area will be presented in Chapter 2.

The next step is to identify the characteristics of infrared emitting diodes which describe or influence the change of peak emission wavelength. Chapter 3 will present information in this area.

Having defined the baseline of infrared emitting diodes as related to wavelength shift, the next appropriate step is to establish a wavelength measurement technique to allow for the determination of wavelength change of pulse operated infrared emitting diodes. This information will be presented in Chapter 4.

Having established a wavelength measurement technique, the next step is to measure values of transient thermal resistance for an infrared emitting diode and compare predicted values of peak emission wavelength against measured values. This information will be presented in Chapter 5.

Finally, the conclusion of the research effort will be presented in Chapter 6.

CHAPTER 2

SEMICONDUCTOR LIGHT EMISSION

2.1 General Information

The history of semiconductor light emission goes back to the early 1900's. Mims (1) relates that an electrical engineer named Henry J. Round, in 1907, touched two wires connected to a battery across a crystal of silicon carbide and observed that the crystal emitted yellowish light. Although Round may not have realized it at the time, he had operated the first crude light emitting diode. A period of 55 years followed when in 1962, as presented by Gooch (2), Hall and co-workers at the General Electric Research Laboratories in Schenectady, New York, succeeded in making the first semiconductor laser which followed the ruby laser in 1960 and the gas laser in 1961.

The above mentioned semiconductor light emission sources, namely, light emitting diodes and semiconductor lasers, are similar in that their operation is based on an electrical current being passed through a p-n junction. The major difference is that the light emitting diode is an incoherent radiation source while the semiconductor laser, as the name implies, is a coherent radiation

source. Besides the p-n junction semiconductor laser, there are other types of semiconductor lasers, such as those presented by Sze (3), which employ optical, electron beam and avalanche breakdown methods to achieve laser action.

The infrared emitting diode, whose pulse operation wavelength characteristics are the subject of this report, followed the light emitting diode in development and is identical in operation with the exception that the radiated emission is in the infrared portion of the spectrum.

Information regarding the physics of light and infrared emitting diodes and semiconductor lasers is readily available and therefore will not be presented in this report except when revelent to the research effort.

2.2 Light and Infrared Emitting Diodes

The light emitting diode (sometimes referred to as luminescent diode) and the infrared emitting diode are much simpler than the semiconductor laser. They are semiconductor diodes which emit visible and infrared energy when forward biased.

There are many types of structural configurations for light and infrared emitting diodes. Configurations include flat, mesa, dome and optical fiber emitter designs. Two flat emitter configurations are illustrated in Figure 1. The n-type material is selected to be

relatively transparent at the emission wavelength.
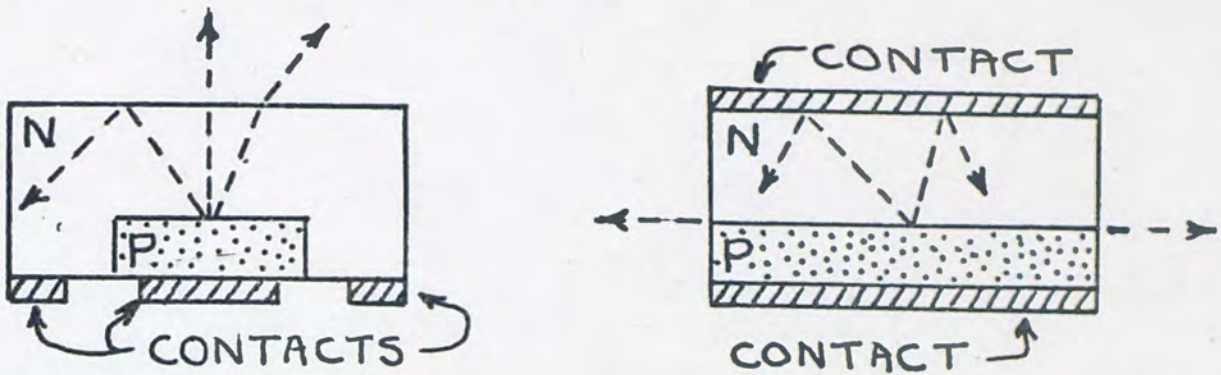
(a) Planar surface emitter   (b) Edge emitter

Fig. 1   Light and infrared emitting
diode flat configurations

A typical curve for output power as a function of
forward current is shown in Figure 2 for the continuous
operation of light and infrared emitting diodes. The
radiation starts at low values of forward current and
increases nearly linearly until the output decreases due
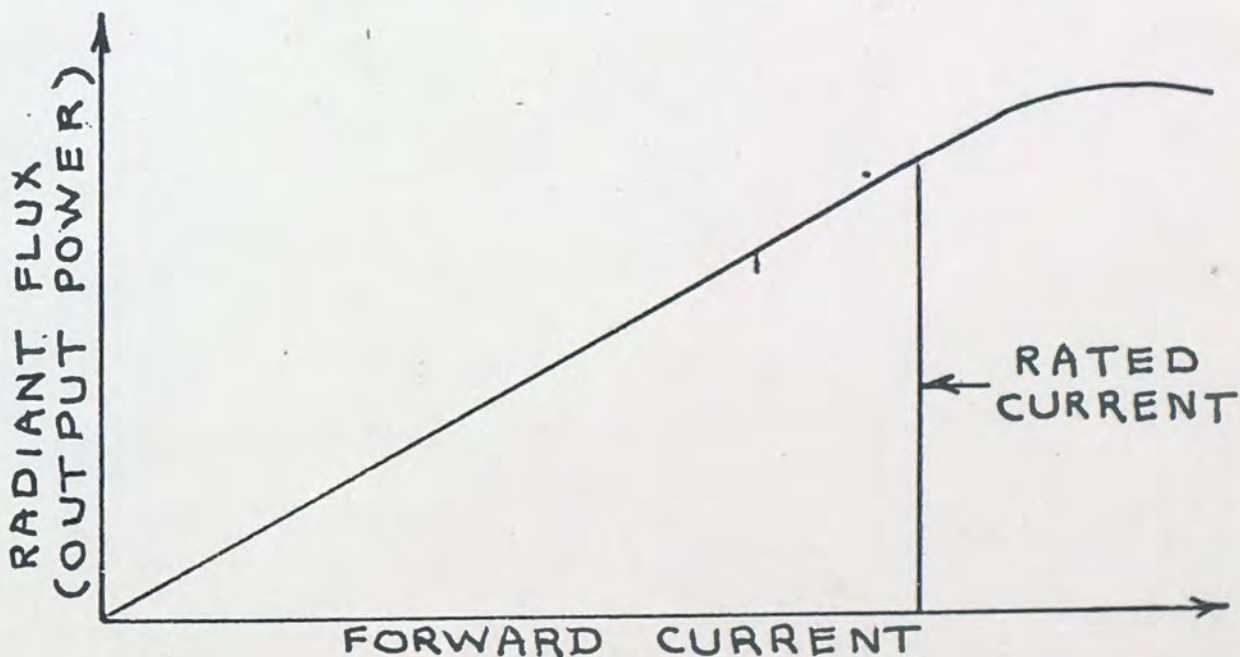to overheating or saturation of the light-emitting process.

Fig. 2   Radiant flux versus forward current for
typical light and infrared emitting diodes

The light and infrared emitting diodes may also be operated in the pulse mode. Additional information in this area will be presented in Chapter 3.

The wavelength of photon emission, λ, is given as

$$\lambda = \frac{h\,c}{E} \tag{2.1}$$

where

$h = 6.624 \times 10^{-34}$ joule-seconds

$c = 3 \times 10^{8}$ meters per second

$E =$ energy in joules that separates the valence and conduction bands in the semiconductor diode

By expressing the denominator of the above equation as E_g, the bandgap separation in electron-volts, we obtain the following

$$\lambda = \frac{1240 \text{ nanometers}}{E_g} \tag{2.2}$$

A well defined bandgap will produce essentially monochromatic radiation. However, the light and infrared emitting diodes have spectral bandwidths (spectral line width between half-intensity points) of typically 25 to 50 nanometers. The wide variation is due to variations in the bandgap and transition levels therein.

By using semiconductors with different bandgaps, it is possible to obtain radiated emission from the blue portion of the visible spectrum to more than 30 micrometers

in the infrared spectrum.

2.3 Semiconductor Lasers

As previously mentioned, there are many types of semiconductor lasers. However, this section will be devoted to one, namely, the injection laser (sometimes called the p-n junction laser), because of its commercial availability and its similarity to light and infrared emitting diodes in being a current dependent diode radiation source.

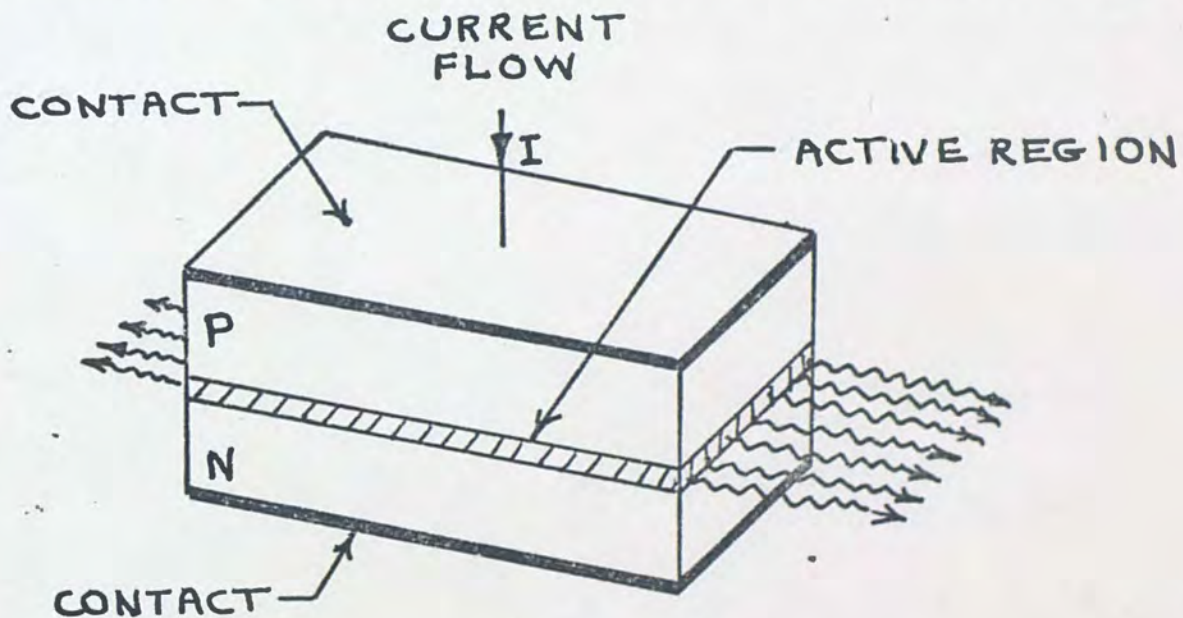The basic configuration of the injection laser is illustrated in Figure 3. It is noted that the presented

Fig. 3 Injection laser configuration

configuration is similar to the flat edge emitter configuration shown for light and infrared emitting diodes. A pair of parallel planes are polished or cleaved perpendicular to the plane of the p-n junction. The two remaining sides of the diode have roughened surfaces to

eliminate lasing in directions other than the main one.
This type of structure is called a Fabry-Perot cavity.

The injection laser operates similarly to an
incoherent emitting diode when operated at low forward
currents. However, as shown in Figure 4, if the forward
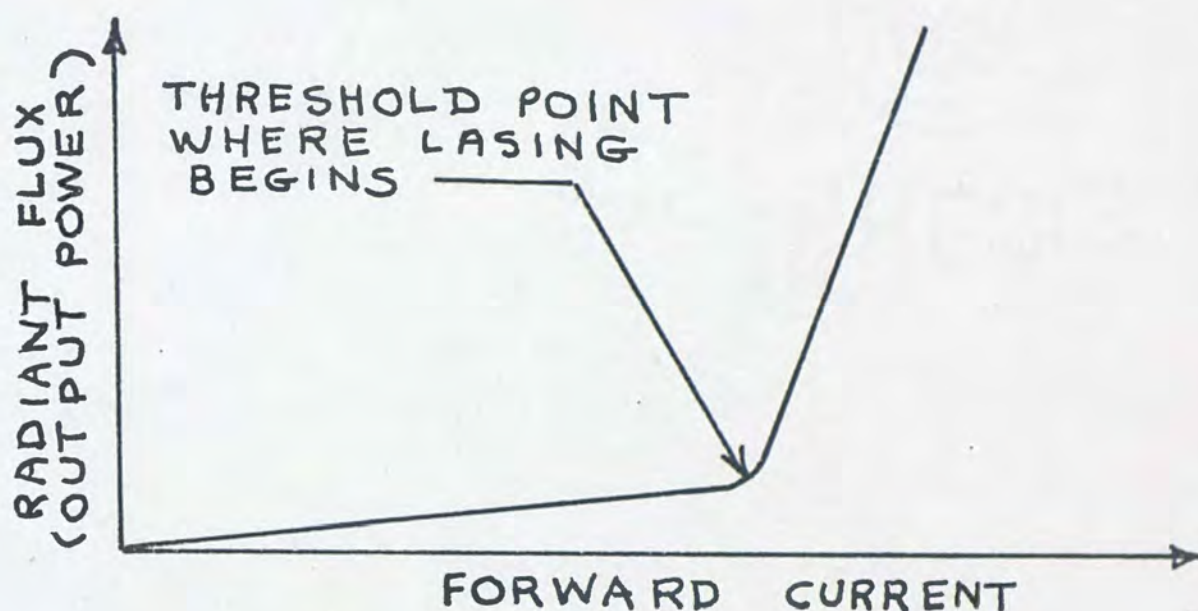
Fig. 4   Radiant flux versus forward current
for a typical injection laser

current exceeds a threshold, lasing occurs and there is a
major change in the slope of the output power versus
forward current curve. Unlike the light and infrared
emitting diodes at room temperature, the p-n junction
laser cannot be operated in the continuous mode. This is
because of the high current densities required to produce
lasing. As reported by RCA Corporation (4), a typical
threshold current is 10 amperes with a peak forward
current being 40 amperes. The current density to produce
lasing can be 10,000 to 20,000 amperes per square

centimeter with the operating current density being typically 50,000 amperes per square centimeter.

Sustained application of these high current densities would cause a very rapid rise in junction temperature, quenching of the lasing action and eventual destruction of the diode. Therefore, p-n junction lasers must be operated only in the pulse mode and within the specified maximum pulse duration and duty cycle. Typical values for p-n junction laser maximum pulse duration and duty factor are 2 microseconds and 0.1 percent respectively.

The p-n junction laser mentioned above is referred to as a homostructure injection laser because it is made -of a single material such as gallium arsenide. The n and p regions are formed by the addition of dopants. An advancement of the p-n junction laser is the heterostructure injection laser which has enabled continuous wave laser operation at room temperature. The basic principle of the heterostructure injection laser is the use of gallium aluminum arsenide in the case of a gallium arsenide laser to form an optical waveguide based on the difference in the index of refraction for each material to contain the light emission in the active region. The result is a decrease in the threshold current sufficient to allow operation at room temperature in the continuous mode.

Similar to the light and infrared emitting diode, the emitted radiation of the injection laser is generated

by a process of recombination. The emission wavelength
is determined by the bandgap and the doping of the
semiconductor.

The spectral bandwidth of an injection laser is
typically 3.5 nanometers which is approximately one-tenth
that of light and infrared emitting diodes.

CHAPTER 3

INFRARED EMITTING DIODE
WAVELENGTH CHARACTERISTICS

3.1 General Information

As previously stated, the area of interest of this report is the change in peak emission wavelength caused by the temperature rise of the diode junction during the application of a current pulse. Because of the common use of gallium arsenide for infrared emitting diodes, this report will limit discussion to that type material.

The peak emission wavelength data as given for gallium arsenide infrared emitting diodes by manufacturers is based on steady state conditions. Table 3-1 presents emission wavelength data for some common infrared emitting diodes.

Table 3-1. Emission Wavelength Data

Manufacturer	Type	Peak Wavelength	Forward Current	Temperature
Texas Instruments	TIXL27	940 nm	300 mA	25°C-stud
Texas Instruments	TIL26	930 nm	35 mA	25°C-air
Spectronics	SE3453	940 nm	100 mA	25°C-case
General Electric	LED56	940 nm	100 mA	25°C-case
RCA	SG1004	940 nm	50 mA	27°C-case

As seen from the table, the value of peak emission wavelength is based on maintaining a reference temperature constant for a stated value of forward current. Stud temperature is associated with power type infrared emitting diodes while case temperature is associated with metal case devices. The stud and case type devices are usually mounted on appropriate heat sinks with the stud and case acting as the interface for removal of heat from the diode junction. Air temperature is the reference for plastic enclosed diodes. The importance of this reference temperature is that the wavelength of peak emission, for the specified forward current, varies directly with the change in reference temperature. Typical values of change in wavelength of peak emission versus reference temperature as found on manufacturer data sheets vary between 0.27 and 0.30 nanometers per °C. Additional consideration of this factor will be presented later in this report.

More important is the establishment of a baseline to describe the junction thermal behavior of an infrared emitting diode. The appropriate candidate is the thermal resistance of the diode. This is because the value of thermal resistance relates change of the junction temperature to the input power to the device.

3.2 Thermal Resistance

Thermal resistance is the ratio of temperature rise to the rate at which heat is generated within a device

under steady state conditions. It is noted that some reference material uses the term thermal impedance in place of thermal resistance. The normal units for thermal resistance are °C/W.

As presented by Texas Instruments Incorporated (5), the thermal resistance of an infrared emitting diode is a difficult parameter to calculate accurately but one which can be measured with a reasonable degree of accuracy. The junction temperature can be approximated by

$$T_J = P_D \, \theta_{JR} + T_R \tag{3.1}$$

where

T_J = junction temperature

P_D = input power(forward current times forward voltage)

θ_{JR} = junction to temperature reference thermal resistance

T_R = temperature of reference point

The method used to measure the thermal resistance of a diode is based on the fact that the voltage across a p-n type junction at a fixed forward current varies inversely and almost linearly with the junction temperature. The first step in the measurement process is to calibrate the diode in an oven at a constant forward current. The calibration current is small compared to the maximum allowable forward current specified for continuous direct current operation. The result is a curve of forward

voltage versus junction temperature for the diode which
will be used as a calibration standard. It is important
that the preceding voltage measurement be made after the
junction temperature has reached steady state temperature
in order to minimize measurement error. The next step is
to place the diode on a constant temperature heat sink in
the case of stud and case type devices and in a constant
temperature air environment in the case of plastic enclosed
diodes. Test circuitry capable of interrupting forward
direct current through the diode for periods of 100
microseconds at about a one-percent duty cycle is used
as the basis for providing the additional information
necessary for determining the thermal resistance of the
diode. During the 100 microsecond period, the calibration
current used in the first step is applied to the diode and
the forward voltage is measured for different values of
forward current. As before, the voltage measurement must
be made after the junction temperature reaches the steady
state value. The junction temperature corresponding to
measured values of forward voltage is read from the
previously obtained forward voltage versus junction
temperature curve. In this manner, a plot of junction
temperature versus input power may be obtained by taking
power and forward voltage readings for several values of
forward current. The slope of the obtained curve is the
thermal resistance of the infrared emitting diode.

The thermal resistance of stud and case type infrared emitting diodes is usually specified as θ_{JC} which represents the steady state rise in junction temperature with respect to the case (stud) per watt of applied input power. This is because these type devices are usually operated when mounted on a heat sink. The thermal resistance of plastic enclosed infrared emitting diodes is specified as θ_{JA} since ambient air temperature is used as the reference for determining the temperature rise of the diode junction. In some instances, manufacturers also give the value of θ_{JA} for metal case diodes. This allows for the determination of maximum operating characteristics when a heat sink is not used for the diode cooling but instead ambient air. Typical values of thermal resistance, θ_{JC}, are on the order of 10 to 20 °C/W for power type infrared emitting diodes and 50 to 100 °C/W for metal case types. Typical values of θ_{JA} for plastic enclosed diodes range between 200 and 300 °C/W.

The use of the thermal resistance value for a device is best illustrated by an example. Suppose we have a device with maximum ratings as follows:

Junction temperature	100 °C
Thermal resistance (junction-case)	20 °C/W
Thermal resistance (junction-air)	120 °C/W

The first area of concern will be to determine the junction temperature when the device is operated without

a heat sink in an ambient temperature of 40 $^{\circ}$C and with
an input power of 150 milliwatts. In this case we can use
equation 3.1 which results in

$$T = .150 \text{ W} \times 120 \text{ }^{\circ}\text{C/W} + 40 \text{ }^{\circ}\text{C}$$
$$= 58 \text{ }^{\circ}\text{C}$$

The second part of the example will be to determine
the rating ($^{\circ}$C/W) of the heat sink required to maintain
the junction temperature below the maximum rating when the
input power is 3 watts (assumed to be within the device
safe area of operation) and the ambient temperature is 25
$^{\circ}$C. Again, we use equation 3.1 and the fact that the
thermal resistance, θ_{JR}, is equal to the sum of θ_{JC} and
θ_{HS}, the thermal resistance of the heat sink. Solving
for θ_{HS}, we obtain

$$\theta_{HS} = (T_J - T_A)/P_D - \theta_{JC}$$
$$= (100 \text{ }^{\circ}\text{C} - 25 \text{ }^{\circ}\text{C})/3 \text{ W} - 20 \text{ }^{\circ}\text{C/W}$$
$$= 5 \text{ }^{\circ}\text{C/W}$$

The above example excluded the thermal resistance of
the connection between the case of the device and the heat
sink. The value is on the order of 0.5 $^{\circ}$C/W and is based
on the heat sink having good surface contact with the
device and a thermally conductive grease covering the
entire contact area. This value becomes significant in
many high power device applications, power transistors

in particular, where θ_{JC} may be on the order of 1 °C/W or less.

The concept of thermal resistance is not applicable to pulse operation of infrared emitting diodes when the pulse length is less than the time necessary for the device to reach thermal equilibrium because the steady state value does not take into account the thermal capacity of the device. An approach which seems promising is to look at the application of transient thermal resistance to describe thermal behavior of infrared emitting diodes.

3.3 Transient Thermal Resistance

As presented by Motorola Semiconductor Products Incorporated (6), a time dependent factor r(t) is applied to the steady state thermal resistance value to account for thermal capacity of a device. Thermal resistance, at a given time, is called transient thermal resistance and is given by

$$\theta_{JR}(t) = r(t) \ \theta_{JR} \qquad (3.2)$$

The transient thermal resistance has been determined to be extremely complex when presented as a mathematical expression. The response is, therefore, plotted from empirical data. The value of r(t) is first determined as a function of pulse width for a duty cycle, D, equal to zero where

$$D = \frac{\text{Pulse Width (t)}}{\text{Pulse Repetition Period } (\tau)} \qquad (3.3)$$

A duty cycle of zero for a given pulse width implies an infinite pulse repetition period and allows for single pulse analysis. By applying a step function change in input power for a given pulse width, we can measure junction temperature at the end of the pulse in a manner similar to that employed for determining the thermal resistance of a device. We can then use equation 3.1 with θ_{JR} replaced by $\theta_{JR}(t)$ and then solve for the transient thermal resistance. From equation 3.2, we solve for r(t) as follows

$$r(t) = \theta_{JR}(t) \,/\, \theta_{JR} \qquad (3.4)$$

The above method is repeated for a number of different pulse widths. The procedure is then repeated for different values of duty cycle. The values of r(t), the normalized transient thermal resistance, are then plotted versus pulse width for the selected values of duty cycle. A typical curve of r(t) versus pulse width for a transistor is shown in Figure 5 for duty cycles of 0, 0.1, and 0.5.

An example best illustrates the use of transient thermal resistance data. Assume we are using a transistor which is represented by the curves contained in Figure 5 operating under the following conditions:
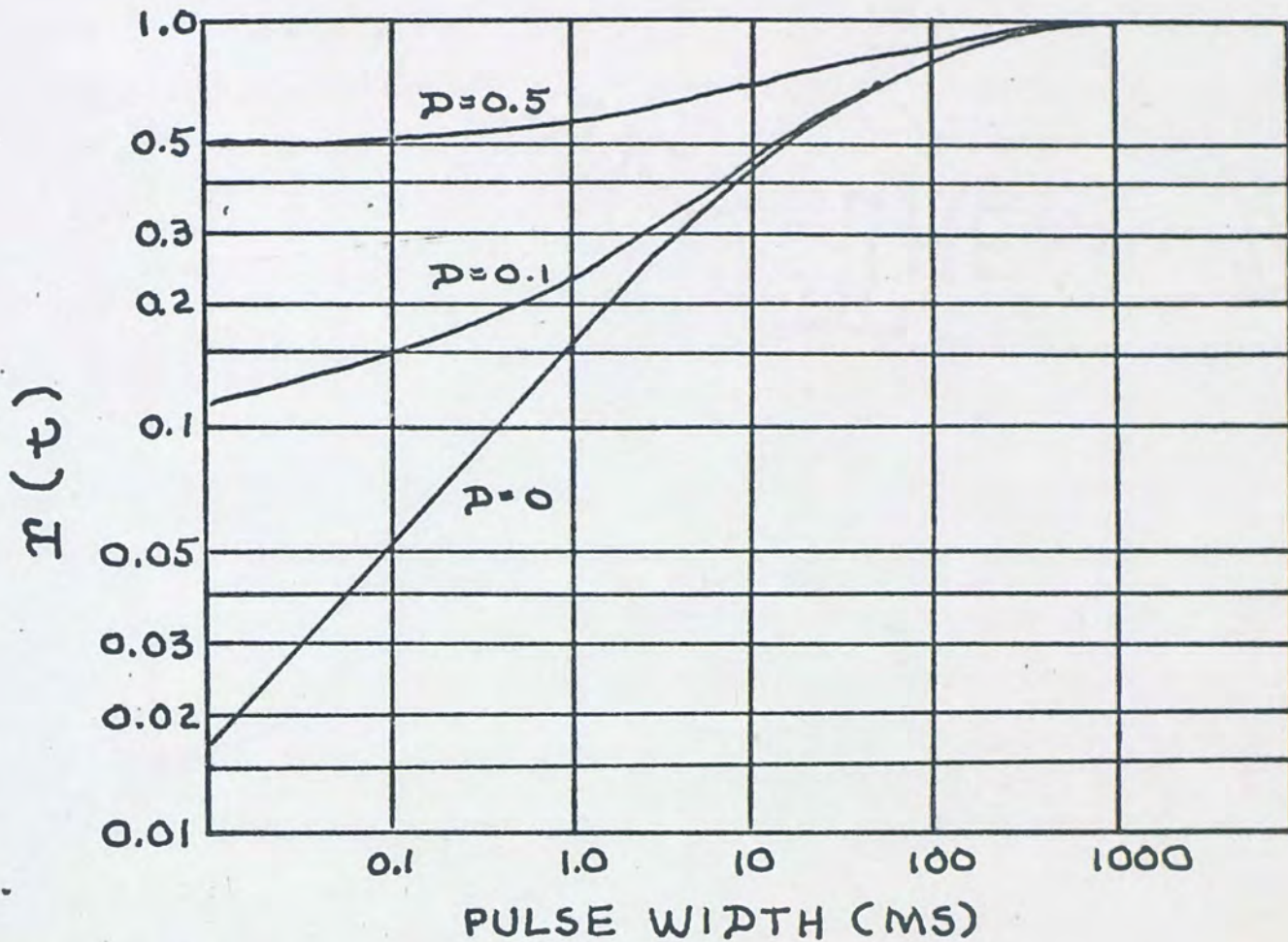
Fig. 5 Typical transistor curves of r(t) versus pulse width for selected duty cycles

Input pulse power	5 W
Pulse duration	1 ms
Pulse repetition period	10 ms
Case temperature (constant)	50 °C
Thermal resistance (junction-case)	35 °C/W

The first part of the example is to find the junction temperature at the end of the first pulse. In this case we can use equation 3.1 with $\theta_{JC}(t)$ substituted for θ_{JR} which results in

$$T_J = r(1 \text{ ms}) \; \theta_{JC} \; P_D + T_C$$

The term $r(1 \text{ ms})$ is read directly from the graph of Figure 5 using the D=0 curve. Therefore we have

$$T_J = .15 \text{ X } 35 \text{ °C/W X } 5 \text{ W} + 50 \text{ °C}$$
$$= 76.25 \text{ °C}$$

The second part of the example is to find the junction temperature at the end of a pulse under steady state conditions. In this case we see that the duty cycle is 0.1. We therefore obtain the value of $r(1 \text{ ms})$ from the D=0.1 curve which results in

$$T_J = .23 \text{ X } 35 \text{ °C/W X } 5 \text{ W} + 50 \text{ °C}$$
$$= 90.25 \text{ °C}$$

The average junction temperature is given by using the average input power, P_D times D, in equation 3.1 which gives

$$T_{J(AV)} = 35 \text{ °C/W X } .5 \text{ W} + 50 \text{ °C}$$
$$= 67.5 \text{ °C}$$

It is noted that the junction temperature at the end of any power pulse does not equal the sum of the average temperature rise (17.5 °C in this example), the rise due to one pulse (26.25 °C in this example) and the reference temperature because cooling occurs between power pulses.

As seen above, the concept of transient thermal

resistance is a useful tool for analysing the pulse operation behavior of devices. It allows for the use of lower power rated devices for low duty cycle applications.

3.4 Use of Transient Thermal Resistance for Infrared Emitting Diodes

The value of thermal resistance is presently used by manufacturers to describe the steady state behavior of the infrared emitting diode junction temperature. This is made possible by the fact that the radiated power output (which represents a cooling process) is a very small percentage of the input power (typical values range between 0.5 and 2.0 percent) and that the percentage remain fairly constant over the operating range. This is also the case for operating the diode in the pulse mode. Further, any major change in radiation efficiency will produce a very minor change in the power dissipated in the device because of the low efficiency. Therefore, the use of transient thermal resistance is considered a useful technique to describe the behavior of the infrared emitting diode junction temperature.

Since we can use transient thermal resistance to determine the junction temperature of the infrared emitting diode for pulse mode operation, the last remaining area of concern is to describe the variation in peak emission wavelength as a function of junction temperature.

As previously stated, the wavelength of peak emission for an infrared emitting diode, for a fixed forward current, varies directly with reference temperature. For gallium arsenide type light emitting diodes, this variation is linear. The problem is that manufacturers data expresses the change in peak emission wavelength as a function of the stud or case temperature and not the junction temperature. As it turns out, the stated value is slightly lower than the desired value. The actual value of peak emission wavelength change per unit change in junction temperature can be obtained from the characteristics of the diode.

Consider a typical infrared emitting diode with the following stated characteristics:

Forward current (continuous)	100 ma
Thermal resistance (junction-case)	75°C/W
Wavelength temperature coefficient (case temperature at stated forward current)	0.28 nm/°C
Forward voltage temperature coefficient (at stated forward current)	-1.8 mv/°C

Assume that we have a 50 °C change in the case temperature. We see that for the stated forward current the forward voltage drop across the diode decreases by 90 millivolts. This represents a decrease in input power of 9 milliwatts. This implies by use of the stated

thermal resistance value that the temperature difference between the case and junction decreased by 0.675 °C. Therefore, the corresponding rise in junction temperature is 49.325 °C which results in a value of 0.284 nanometers per °C for the value of peak emission wavelength change per unit change in junction temperature.

Based on the above, we see that we can use the manufacturers stated value of peak emission wavelength change per unit change in case or stud temperature for a particular diode as a reasonable approximation to describe the peak emission wavelength change per unit change in junction temperature.

3.5 Pulse Mode Operation of Infrared Emitting Diodes

Before one attempts to operate an infrared emitting diode in the pulse mode, a review of some basic factors is in order.

The maximum peak forward current, I_{FPM}, for pulse mode operation can be approximated by

$$I_{FPM} = I_{FM} / D \qquad (3.5)$$

where

I_{FM} = maximum rated continuous forward current

D = duty cycle

As can be seen, if we desire to increase the peak forward current (maximum) while operating the device in

the pulse mode, we must decrease the duty cycle. This implies that we either decrease the pulse width or increase the pulse repetition period or change both parameters to achieve a reduction in duty cycle. The limiting value of maximum peak forward current for pulse operation is usually based on the value of current that will cause bonding wires inside the device to open. This value is specified by manufacturers and is given for a stated pulse width and duty cycle. Typical values are on the order of 5 to 10 amperes.

The approximation of equation 3.5 does not include any consideration of temperature and power dissipation factors. For proper design of a system employing infrared emitting diodes, these factors are very important and should be considered as well as trade-offs such as duty cycle, pulse repetition period and peak current. The manufacturers data sheet should be used as a basis for design with particular attention given to the absolute maximum ratings for the infrared emitting diode.

CHAPTER 4

WAVELENGTH MEASUREMENT TECHNIQUE

4.1 General Information

A sound wavelength measurement technique is
essential to allow for the determination of wavelength
changes associated with pulse operated infrared emitting
diodes. Some important factors to be considered are the
type of instrument to be used for the wavelength
measurement, the input optical system to be used to match
the source to the wavelength measurement instrument and
the technique used to measure the wavelength measurement
instrument output.

4.2 Wavelength Measurement Instrument

The wavelength measurement instrument available
to measure the peak emission wavelength change of
infrared emitting diodes is the Hilger-Engis Model 1000
Monochromator Spectrometer. The unit is a plane grating,
symmetrical Czerny-Turner spectrometer in which radiation
transmitted through the entrance slit is collimated and
directed toward the diffraction grating by a collimating
mirror. The diffraction grating disperses the incident
radiation and part of the dispersed radiation falls onto a
focusing mirror which directs and focuses the spectrum to

and at the exit slit. The layout of the Czerny-Turner spectrometer is illustrated in Figure 6. The focal length for both the collimating and focusing mirror is one meter.
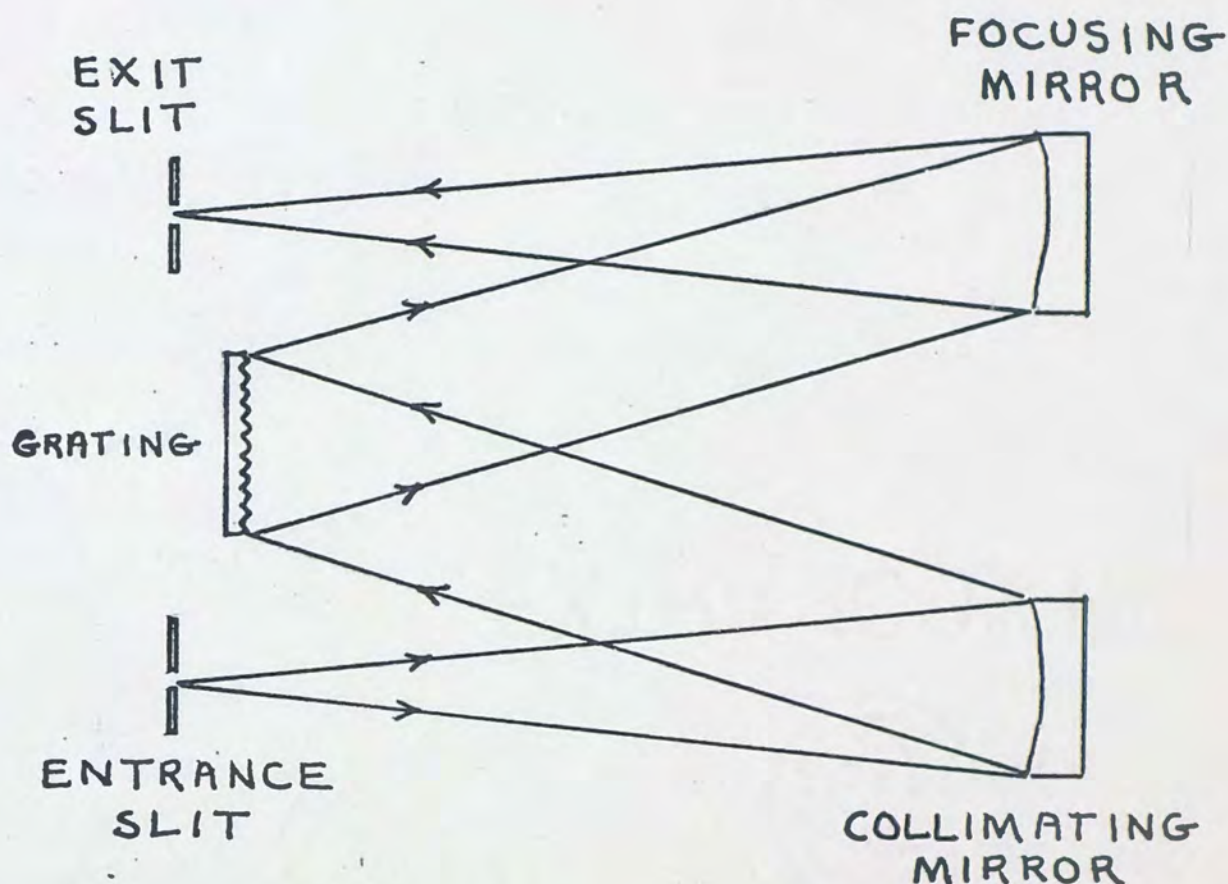

Fig. 6 Layout of Czerny-
Turner spectrometer

For changing the wavelength band passing through the exit slit, the diffraction grating is rotated either by a manual drive or by a motor drive. The wavelength of the outgoing radiation is indicated by a mechanical counter, directly in angstroms. By changing diffraction gratings, the spectrometer can be used over the wavelength range of 185 nanometers to 30 micrometers.

The instrument will be used with a one micrometer diffraction grating (first order blaze wavelength) which provides high efficiency in the radiation spectrum of gallium arsenide infrared emitting diodes.

4.3 Input Optical System

Davis (7) discusses the importance of input slit illumination since the illumination of the slit and the slit width determine how much radiated energy enters the spectrometer and produces a useful diffraction pattern. The solid angle of radiated energy, Ω, accepted by the spectrometer is determined by the size of the diffraction grating and the focal length of the collimating mirror. This solid angle must be geometrically filled with radiated energy from the source, at the very least, in order to utilize the instrument properly. If an image of the source is focused on the slit, the solid angle of radiated energy from the input lens system, Ω_{LS}, must be at least as large as the solid angle of the spectrometer, as shown in Figure 7.

A typical optical design for the input optical system is best illustrated by an example. Suppose we have a source which radiates into a solid angle of 0.04 π steradians and desire to design an input optical system using 40 millimeter diameter lenses which properly illuminates the input slit of the spectrometer. An input optical system design to achieve the stated objectives is

SOURCE

INPUT
SLIT

COLLIMATING
MIRROR

INPUT
LENS
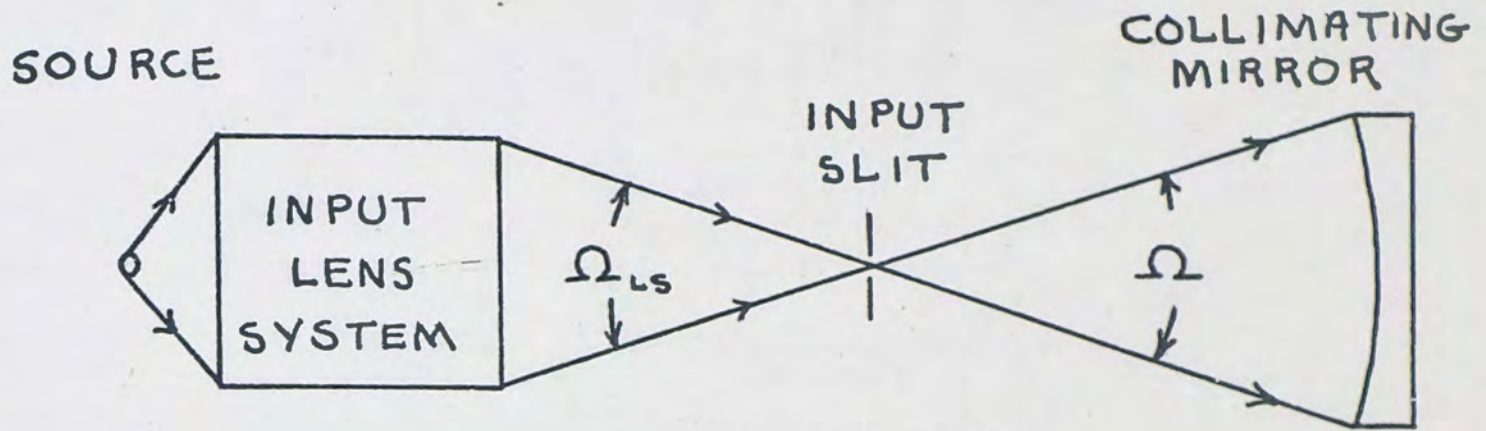SYSTEM

Ω_{LS}

Ω

Fig. 7   Illumination of spectrometer

illustrated in Figure 8 where f_{CL} is equal to the focal
length of the collimating lens and the distance between
the lens and the source, f_{FL} is equal to the focal length
of the focusing lens and the distance between the lens and
input slit, d is equal to the lens diameter and l is
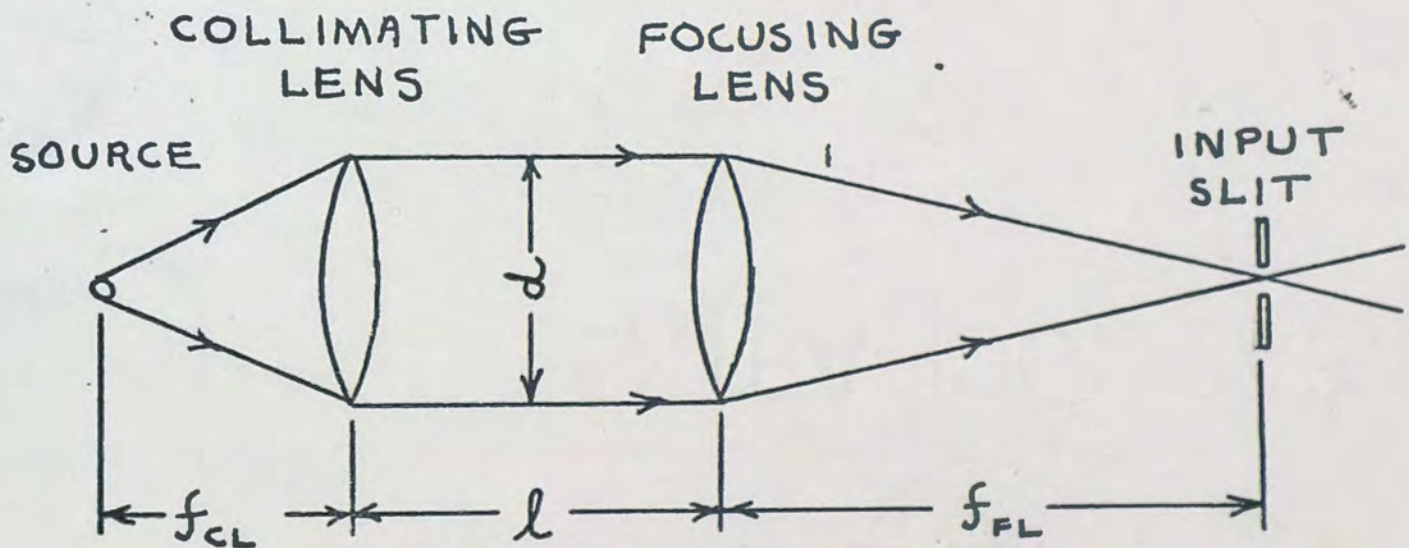equal to the separation between the lenses.

COLLIMATING
LENS

FOCUSING
LENS

SOURCE

INPUT
SLIT

d

f_{CL}

l

f_{FL}

Fig. 8   Input optical system design

The first step will be to calculate the value of f_{CL}. We can make use of the fact that solid angle is defined as the surface area at a given radius divided by the square of the radius. This results in

$$\Omega = \pi (d/2)^2 / f_{CL}^2 \tag{4.1}$$

Solving for f_{CL}, we obtain

$$
\begin{aligned}
&= \sqrt{\pi/\Omega} \; d/2 \\
&= \sqrt{\pi/0.04\pi} \;\; 4/2 \text{ cm} \\
&= 10 \text{ cm}
\end{aligned}
$$

The next step is to calculate the value of f_{FL}. Here we make use of the fact that the f/number of the spectrometer must equal the f/number of the focusing lens. The latter is given by

$$\text{f/number} = f_{FL} / d \tag{4.2}$$

The f/number for the spectrometer is found to be 10 from the manufacturers data for a measurement wavelength of 940 nanometers. Solving equation 4.2 for f_{FL} gives

$$
\begin{aligned}
f_{FL} &= 10 \; d \\
&= 40 \text{ cm}
\end{aligned}
$$

The value of l is not critical but should be kept small in order to minimize design problems.

It is pointed out that this same design concept is

applicable to the output of the spectrometer. A
collimating lens can be used to collimate the diverging
output of the spectrometer while a second focusing lens
can provide for imaging of the slit onto a sample (useful
for absorption spectroscopy).

The input slit width to be used depends on the
method of slit illumination, the fraction of theoretical
resolution desired and the required throughput. These
factors must be carefully considered in order to provide
the basis required for wavelength measurement.

While not a problem for our application since we
have a single wavelength source, a problem sometimes
occurs when the spectrometer is used to measure specific
wavelengths of a source with a wide spectral range. The
result is an overlapping of orders which occurs when
different wavelengths appear at the same angle but in
different orders. For example, if a spectrum at 750
nanometers is to be observed in the first order,
wavelengths of 375 and 250 nanometers will appear at
exactly the same angle. There must be some auxiliary
dispersion or filtering to separate these orders if
overlapping is to be avoided. Usually combinations of
transmission filters (input filtering) and photographic
emulsion (output filtering) are used to properly separate
overlapping orders. Another technique is a use of a prism
predisperser to select the spectral wavelength range of

interest.

4.4 <u>Output Measurement</u>

There are many output measurement techniques available to determine the output emission of a spectrometer. The major point to be made in this area is that the output to be measured is a function of the diffraction grating efficiency (which is a function of wavelength). To complicate the matter, the measurement device (eye, photodiode, photomultiplier tube, photographic film, etc.) also has a sensitivity which is a function of wavelength. Therefore, extreme care must be taken when comparing measured or observed relative values of spectral emission, especially when there is a large difference in wavelength.

CHAPTER 5

EXPERIMENTAL MEASUREMENTS

5.1 General Information

The experimental measurements cover two areas. The first is the pulse mode operation measurement of values of transient thermal resistance of an infrared emitting diode. Measurements will be taken for different values of pulse width and duty cycle. The second is to compare transient thermal resistance predicted values of peak emission wavelength change against measured values.

5.2 Transient Thermal Resistance Measurements

The infrared emitting diode selected for transient thermal resistance measurements was the Monsanto ME 7140 type because it is typical of a wide variety of other devices.

The first measurement procedure was to obtain the forward voltage versus temperature curve for a constant forward current, in this case 10 milliamperes. The purpose was to provide a baseline to determine the actual junction temperature of the infrared emitting diode at the end of a current pulse. The basic calibration circuit is shown in Figure 9. The oven temperature was measured using a copper-constantan thermocouple and a digital
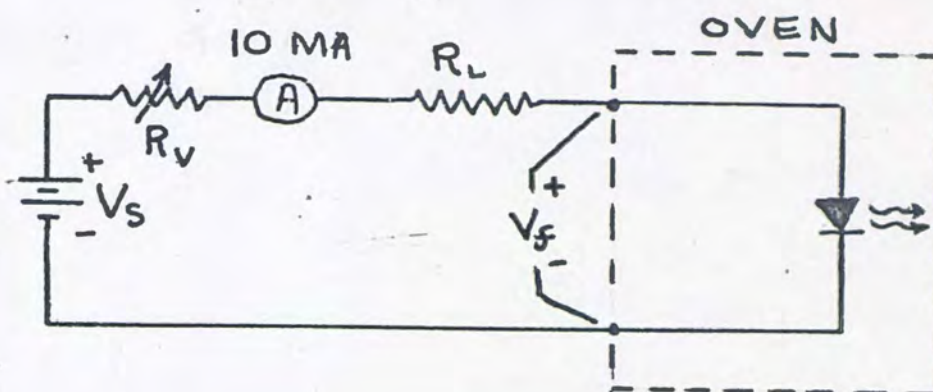
Fig. 9 Forward voltage versus
junction temperature calibration
circuit

temperature indicator. A digital voltmeter was used to
measure the forward voltage of the diode and a laboratory
type milliammeter was used to measure the diode forward
current. The resistor R_L is for overload current
protection while R_v is used to maintain the 10 milliampere
forward current.

As expected, the resulting data showed the variation
in forward voltage over a temperature range from 25°C to
75°C to vary linearly with temperature. The measured
forward voltage temperature coefficient was -1.76 mv/°C
as compared to the manufacturers stated value of -1.8 mv/°C.

Having defined a baseline to measure the junction
temperature at the end of a current pulse, the next step
was to build a measurement circuit to obtain data to
calculate values of transient thermal resistance. This

circuit is presented in Figure 10. A continuous forward current of 10 milliamperes is passed through the diode when the transistor is turned off. This enables the
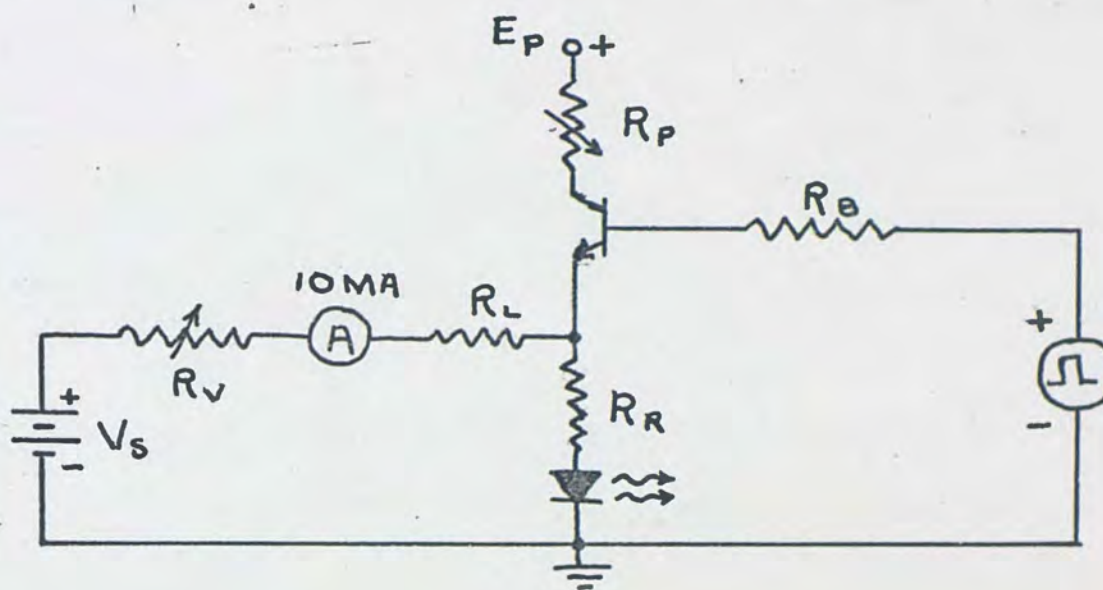

Fig. 10   Transient thermal resistance
data measurement circuit

determination of the junction temperature by measuring the forward voltage across the diode and finding the corresponding temperature on the calibration graph. During the application of a current pulse through the transistor driver circuit, the junction temperature rises to a value dependent on the transient thermal resistance of the diode. If we place an oscilloscope across the diode, we can measure the forward voltage immediately after the input pulse goes to zero and obtain the junction temperature at the end of the applied pulse. This approach was not used, however, because of the small

variation in forward voltage observed during the
measurement process. Instead, a measurement was made of
the change in forward voltage at the end of a current pulse
with respect to the ambient (no pulse input) forward
voltage. A plot of these measurements is presented in
Figure 11, and represents the application of a 7.58 watt
power pulse. The rise at the end of the curve is due to
the fact that the junction temperature did not return to
ambient temperature prior to the application of the next
pulse. Pulse current was measured by interchanging the
diode and R_R, a one ohm resistor, and measuring the
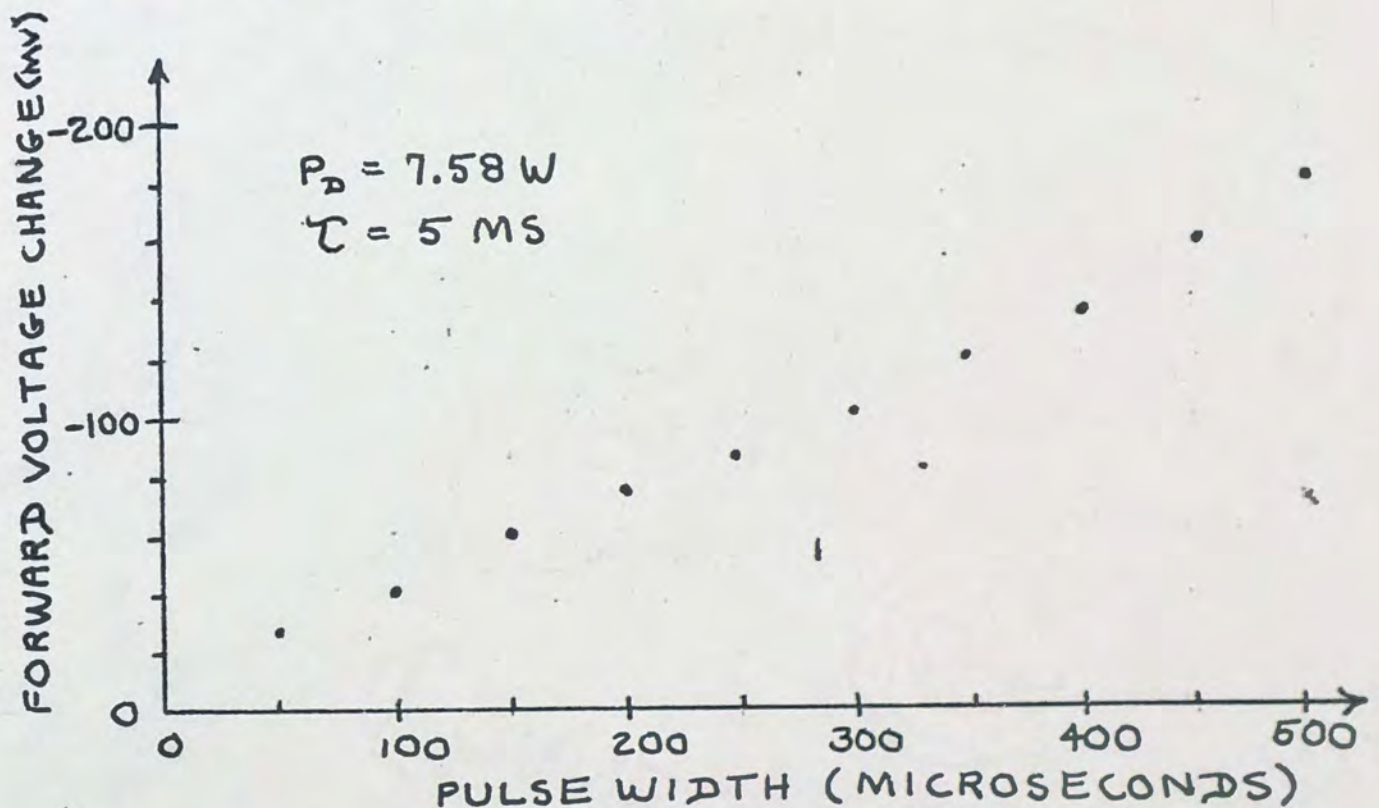voltage drop across the resistor.

Fig. 11 Forward voltage variation
as a function of pulse width

The value of $\theta_{JA}(t)$ was calculated using equation 3.1

with $\theta_{JA}(t)$ substituted for θ_{JR} and T_A substituted for T_R. The value of $T_J - T_A$ was determined by dividing the measured voltage contained in Figure 11 by 1.76 millivolts. A summary of the calculated values of $\theta_{JA}(t)$ are presented in Table 5-1, for various pulse conditions.

Table 5-1. Summary of Results

Pulse Width (microseconds)	Duty Cycle	$\theta_{JA}(t)$ °C/W
50	.01	1.87
100	.02	2.99
150	.03	4.49
200	.04	5.62
250	.05	6.37
300	.06	7.49
350	.07	8.99
400	.08	10.11
450	.09	11.99
500	.10	13.11

5.3 Wavelength Measurements

The first procedure was to check the spectrometer to insure that all components were properly mounted and that the various image planes were properly centered. Some small adjustments were required and were accomplished in accordance with the information contained in the instruction manual.

The next step was to calibrate the measurement

instrument. This was accomplished by using a low pressure mercury lamp and its associated 546.07 nanometer visible line image at the spectrometer wavelength settings of 546.07 and 1,092.15 nanometers and moving the focusing mirror and grating holder adjustments in accordance with the information contained in the instruction manual.

The peak emission wavelength change of some light and infrared emitting diodes were measured as a function of forward current in the continuous mode of operation. The output of the spectrometer was measured with an optical power meter since the photomultiplier tubes available for use with the spectrometer were not responsive in the 940 nanometer region of the spectrum. The observed results were in good agreement with the values predicted by using the manufacturers stated values of thermal resistance, θ_{JA}, and the wavelength temperature coefficient (case temperature). The input optical system design described in Chapter 4 was used as a basis to couple the source to the spectrometer and produced very good results.

The concept to measure the wavelength shift for pulse mode operation of infrared emitting diodes was to observe and record the maximum voltage output from a photomultiplier tube or photodiode detection circuit and plot the information on a graph. The expected results are illustrated in Figure 12 with the change in wavelength
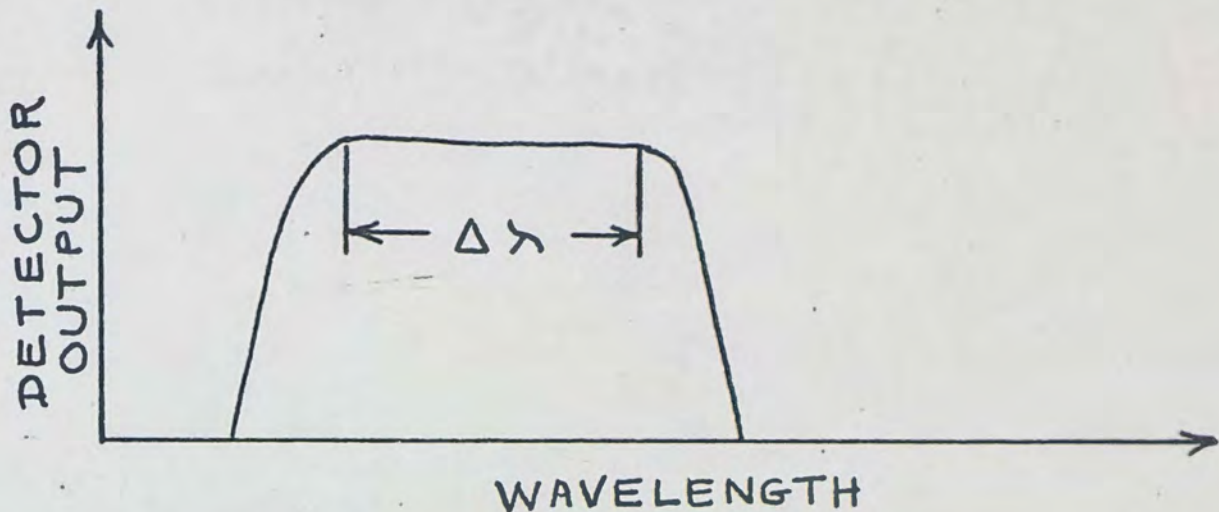
Fig. 12   Plot of maximum detector
output versus wavelength for a given
pulse power, duration and repetition
period

during the application of a pulse, $\Delta\lambda$, being estimated
from the graph.

An attempt was made to build a photodiode detector
and to use an existing one, both without success. Based
on this and the non-availability of any other infrared
detection equipment for pulse mode operation, no
experimental measurements were taken to compare transient
thermal resistance predicted values of peak emission
wavelength change against measured values.

CHAPTER 6

CONCLUSION

6.1 Discussion

The research effort has shown that the use of transient thermal resistance is an applicable technique to describe the temperature behavior of an infrared emitting diode junction when the device is operated in the pulse mode. This being the case, we can also use this data to determine the peak emission wavelength change of the diode for pulse mode operation. It is felt that with an appropriate infrared detector, the above would have been demonstrated by experimental measurement.

In summary, the research effort has been very interesting and has proved itself beneficial in work related projects.

6.2 Application of Research Effort

A potential application for the use of infrared emitting diodes based on the knowledge gained from this research effort is for a remote temperature sensing system. While the idea has not been investigated to any great detail, it appears to have some practical uses.

The general concept is to make use of the diode's change in emission wavelength as a function of temperature.

By operating the device in the pulse mode to increase output power and coupling the diode to a suitable detector, say by means of an optical fiber, we could monitor the wavelength and determine the remote temperature. A means to monitor the wavelength could be by the use of narrow band optical filters.

6.3 Recommendations

The Hilger-Engis Model 1000 Monochromator Spectrometer is an excellent device with which to perform optical measurements. To improve its usefulness, it is recommended that the following accessories be purchased:

    (a) Photomultiplier tube and attachment for near infrared measurements

    (b) Accessory bar

    (c) Bar carriages

    (d) Focusable eyepiece

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