ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2011 SESSION

Open-book examination
Calculators: only authorized models
Duration: 3 hours

07–ELEC–B10 Electro-optical engineering

Problem 1 (25 points)

You consider an infrared source made by *Opto Diode Corp.* (model OD-669) in order to provide the necessary lighting in a night vision system you are designing. Technical specifications for this device are provided at the end of the test.

a) (15 points) You must study 2 distinct operating conditions: a continuous operation under a current of 300 mA and a pulsed operation with a peak current of 5 A (pulses last for 10 µs at a frequency of 100 Hz). Determine the electrical efficiencies of the source under these 2 operating conditions. Which one is the most efficient?

b) (10 points) Under which operating condition will the source suffer the largest temperature increase? Justify your answer.

Problem 2 (25 points)

An optical communications system must operate with a bit error rate smaller than 10^{-9}. The transmitter of this system has a laser operating at a wavelength of 1.55 µm. It injects a power of −8.5 dBm into an optical fiber which losses are 0.2 dB/km. At the other end of the optical link is the system receiver built around a fast photodiode. This photodetector is model GCR103-XX1 from *Ultrafast Sensors & Applications.* Its responsivity at the laser wavelength is 0.95 A/W, it has a response time of 0.045 ns and its dark current is 100 pA. The noise level of the photodetector has been carefully calculated by a colleague and it is of 10.7 nA.

What is the maximum length of the optical fiber in order to ensure that the communications system meets its performance requirements?

Problem 3 (25 points)

The time evolution of the charge carrier density in the active region of a semiconductor laser $N(t)$ is given by the following differential equation:

$$\frac{\mathrm{d}N(t)}{\mathrm{d}t} = \frac{J(t)}{ed} - \frac{N(t)}{\tau_c} - G(t)S(t),$$

where $J(t)$ is the current density crossing the junction, e is the elementary charge, d is the thickness of the active region, τ_c is the carrier lifetime, $G(t)$ is the material gain and $S(t)$ is the density of photons present in the active region. Material gain is proportional to carrier density:

$$G(t) = g\,[N(t) - N_{tr}]\,,$$

where g is the linear coefficient and N_{tr} is the carrier density enabling transparency of the medium.

You are particularly interested into the power buildup of the laser, i.e. the delay between the application of the current and the presence of a significant lasing action.

a) (10 points) Prove that the current bringing the laser to its oscillation threshold is:

$$I_{th} = Aed\frac{N_{th}}{\tau_c},$$

where A is the area of the contact surface of the laser and the carrier density at threshold N_{th} is related to the threshold gain G_{th}:

$$N_{th} = \frac{G_{th}}{g} + N_{tr}.$$

b) (10 points) Prove that the turn-on delay of the laser is given by the following relation:

$$t_{to} = \tau_c \ln\left(\frac{I}{I - I_{th}}\right).$$

c) (5 points) Under which current will the turn-on delay be smaller than 2 ns, assuming the carrier lifetime is 4 ns?

Problem 4 (25 points)

You experimentally characterized the noise behavior of a photodiode with a system whose bandwidth was limited by a 1st-order filter having a cut-off frequency of 1 MHz. Your results are given in Table 4–a.

Table 4–a – Measurements of the current noise of a photodiode.

optical power P_{opt} [µW]	*standard deviation* σ_I [nA]
1.1	1.7
12.1	2.5
22.6	3.2
33.2	3.8
43.7	4.1
53.8	4.5
64.3	5.0

You must work under the hypothesis that only 2 noise sources are present: shot noise due to the photocurrent and thermal noise due to the detector equivalent resistance.

a) (17 points) Knowing that the measurements were realized with a laser whose wavelength was 1.3 µm, estimate the detector quantum efficiency.

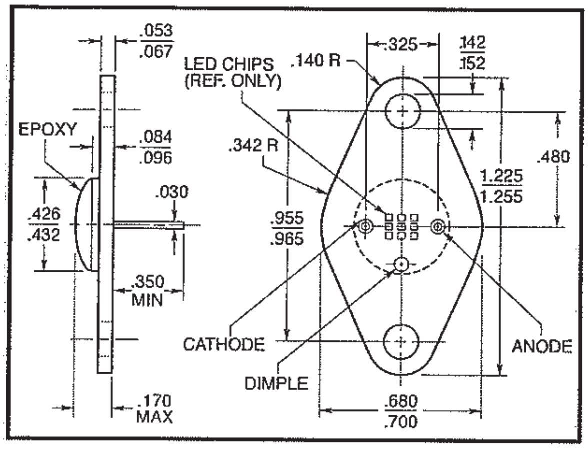
b) (8 points) Knowing that the detector temperature was 0 °C, estimate its equivalent resistance.

Glossary

termes français	*English terms*
amorce	power buildup
bruit	noise
bruit de grenaille	shot noise
bruit thermique	thermal noise
courant de noirceur	dark current
densité de courant	current density
densité de porteurs	carrier density
fibre optique	optical fiber
fréquence de coupure	cut-off frequency
gain linéique du matériau	material gain
infrarouge	infrared
laser à semi-conducteurs	semiconductor laser
lien optique	optical link
longueur d'onde	wavelength
pertes	losses
photocourant	photocurrent
photodétecteur	photodetector
photodiode	photodiode
porteurs de charge	charge carriers
puissance	power
rendement	efficiency
rendement quantique	quantum efficiency
récepteur	receiver
région active	active region
résistance	resistance
responsivité	responsivity
semi-conducteur	semiconductor
seuil	threshold
taux d'erreur binaire	bit error rate
temps de vie	lifetime
transmetteur	transmitter
valeur crête	peak value

— End of exam —

HIGH-POWER GaAIAs IRLED ILLUMINATOR **OD-669**



FEATURES

- Highest power output available
- 880nm peak emission
- Nine chips connected in series
- Very wide angle of emission
- Electrically isolated case

All surfaces are gold plated. Dimensions are nominal values in inches unless otherwise specified.

ELECTRO-OPTICAL CHARACTERISTICS AT 25°C

PARAMETERS	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Total Power Output, P_o	$I_F = 300mA$ $I_F = 5A$	390	500 6500		mW
Peak Emission Wavelength, λ_P	$I_F = 50mA$		880		nm
Spectral Bandwidth at 50%, $\Delta\lambda$			80		nm
Half Intensity Beam Angle, θ			120		Deg
Forward Voltage, V_F	$I_F = 300mA$		13.5	15	Volts
Reverse Breakdown Voltage, V_R	$I_R = 10\mu A$	5	30		Volts
Capacitance, C	$V_R = 0V$		11		pF
Rise Time			3		μsec
Fall Time			3		μsec

ABSOLUTE MAXIMUM RATINGS AT 25°C CASE

Power Dissipation[1]	6W
Continuous Forward Current	400mA
Peak Forward Current (10μs, 400Hz)[2]	5A
Reverse Voltage	5V
Lead Soldering Temperature (1/16" from case for 10sec)	260°C

[1]Derate per Thermal Derating Curve above 25°C
[2]Derate linearly above 25°C

THERMAL PARAMETERS

Storage and Operating Temperature Range	-55°C to 100°C
Maximum Junction Temperature	100°C
Thermal Resistance, R_{THJA}[1]	60°C/W Typical
Thermal Resistance, R_{THJA}[2]	16°C/W Typical

[1]Heat transfer minimized by measuring in still air with minimum heat conducting through leads
[2]Air circulating at a rapid rate to keep case temperature at 25°C

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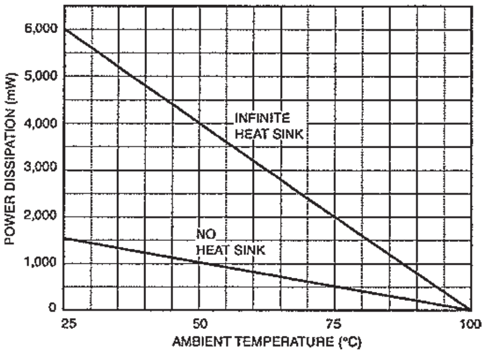
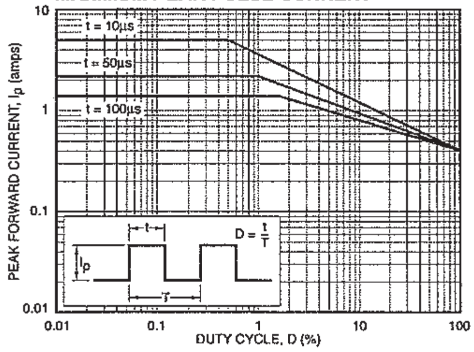
MAXIMUM RATINGS

THERMAL DERATING CURVE

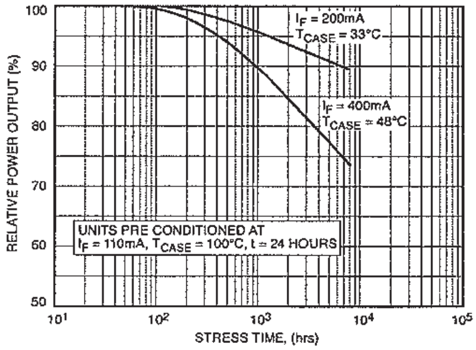


MAXIMUM PEAK PULSE CURRENT

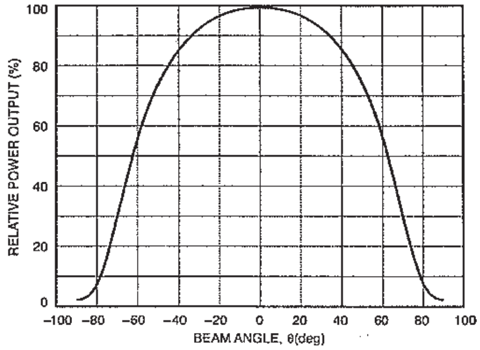


TYPICAL CHARACTERISTICS

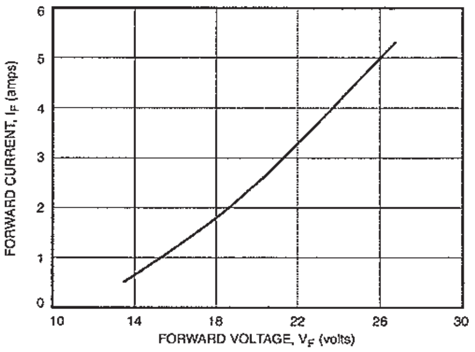
DEGRADATION CURVE



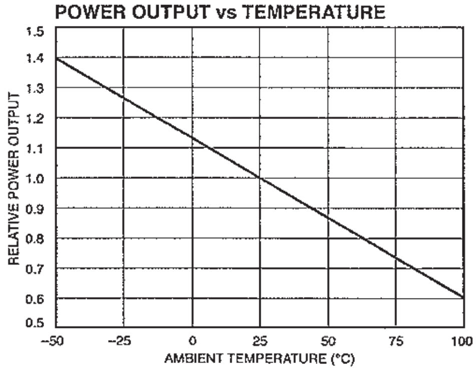
RADIATION PATTERN



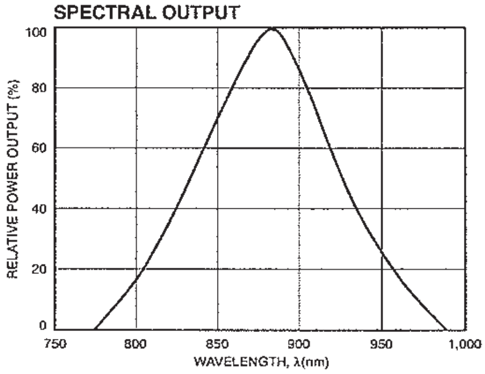
FORWARD I-V CHARACTERISTICS



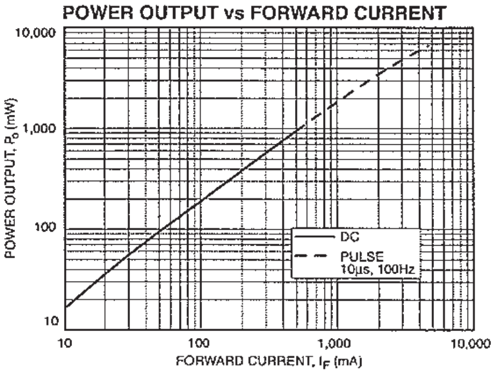
POWER OUTPUT vs TEMPERATURE



SPECTRAL OUTPUT



POWER OUTPUT vs FORWARD CURRENT



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