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Characteristics of GaAsSb Single Quantum Well Lasers Emitting Near 1.3 μm

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ABSTRACT

We report data on GaAsSb single quantum well lasers grown on GaAs substrates. Room temperature pulsed emission at 1.275 μm in a 1250 μm-long device has been observed. Minimum threshold current densities of 535 A/cm^2 were measured in 2000 μm long lasers. We also measured internal losses of 2-5 cm^{-1}, internal quantum efficiencies of 30-38% and characteristic temperatures T_0 of 67-77°C. From these parameters a gain constant G_0 of 1660 cm^{-1} and a transparency current density J_{tr} of 134 A/cm^2 were calculated. The results indicate the potential for fabricating 1.3 μm VCSELs from these materials.

DISCLAIMER

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Long-wavelength vertical-cavity surface-emitting lasers (VCSEL) are increasingly desirable for optical interconnect and optical communications applications. To date, practical VCSEL devices have been limited to operation at wavelengths less than 1 μm due to the inability to simultaneously achieve high refractive index contrast and high material gain at longer wavelengths for materials grown on a common substrate. Traditionally, materials in the InGaAsP-InP system have been employed to reach wavelengths beyond 1 μm. In this system, materials emitting at 1.3 μm must be grown on InP substrates. Unfortunately, the low index contrast in this material system makes realization of distributed Bragg reflectors (DBRs) difficult. In contrast, the GaAs/AlGaAs material system lends itself well to the construction of highly reflecting DBRs and, in fact, has been key to the development of VCSELs operating at wavelengths ≤1 μm. Furthermore, the use of oxidation technology available in the GaAs/AlGaAs system has greatly improved VCSEL efficiency [1]. For these reasons, it is desirable to employ GaAs/AlGaAs materials in the realization of a 1.3 μm VCSEL as well. Until recently there have been no companion 1.3 μm active region materials which could be grown on GaAs substrates. Instead, approaches such as InGaAsP based active regions wafer-bonded to GaAs-AlGaAs based DBRs have been employed [2]. More recently, significant effort has been devoted to the development of small-bandgap materials that can be grown on GaAs substrates. These include GaInNAs alloys [3] and InAs or InGaAs quantum dots [4]. An alternative scheme involves GaAsSb alloys grown compressively strained on GaAs substrates [5].

In this letter we report on the characteristics of edge emitting lasers containing a single quantum well (SQW) of GaAsSb grown on GaAs substrates. We have measured the characteristic temperature T_0, as well as internal efficiency, losses and wavelength shift as a function of temperature. Furthermore, from these experimental results, we conclude that GaAsSb materials may be a viable approach to obtaining long-wavelength VCSELs.

The laser material was grown by solid-source molecular beam epitaxy on a (100)-oriented Si-doped GaAs substrate. The structure consisted of a single 4.2 nm GaAsSb quantum well with a nominal Sb mole fraction of 0.34 in a 0.22 μm undoped GaAs waveguide region, clad on both sides by 1.5 μm $Al_{0.6}Ga_{0.4}As$ layers. The AlGaAs doping was $2x10^{17}cm^{-3}$ within 0.4 μm of the waveguide region for the p side, and similarly $4x10^{17}$ cm^{-3} for the n side. The doping level was increased to $2x10^{18}$ cm^{-3} further from the active region on both the n and p sides. A 50 nm p+ GaAs cap layer was used to facilitate ohmic contact formation. The layer structure is shown in Fig. 1. Be and Si were used for the p- and n-type dopants, respectively. Cracking effusion sources were used for the As and Sb, producing primarily As_2 and Sb_1 species, respectively. The growth temperature was 610 °C for the AlGaAs and GaAs layers and 490 °C for the GaAsSb quantum well. Broad area, gain guided lasers were fabricated into a variety of stripe widths and lengths.

Fig. 2 shows below- and above-threshold spectra of a 1250 μm long and 75 μm wide stripe laser, taken under pulsed conditions (3 μsec pulse, 10 kHz repetition rate) at room temperature. Lasing occurs at 1.275 μm, while below-threshold low pump intensity electroluminescence peaks at 1.31 μm. Such a substantial blue shift in emission wavelength with pump intensity (26 meV) may be the result of a type-II GaAs/GaAsSb band alignment, as suggested by previous studies [6,7,8]. Alternatively, a weak type-I alignment [5,9] combined with bandfilling in compositionally inhomogeneous GaAsSb may be responsible for this effect.

Fig. 3 shows light output per facet versus drive current (L-I) of a 2000 μm long and 100 μm wide laser. These measurements were taken at room temperature under pulsed conditions (0.5 μsec pulse and 10 kHz repetition rate for all the following figures). The threshold current and external differential quantum efficiency are 1.08 A and 23% respectively. The corresponding threshold current density is 0.53 kA/cm^2 (threshold current density is defined as terminal threshold current divided by the area of the laser). The series resistance, R_s was ~10 Ω in the near-threshold region. The threshold current density extrapolated for an infinite resonator length (for 100 μm wide lasers), was found to be $J_\infty = 0.32$ kA/cm^2.

Fig. 4 shows output power per facet plotted versus the driving current at various temperatures of the heat sink. The laser diode resonator was 1250 μm long and 75 μm wide. The threshold current densities varied from 0.72 kA/cm^2 at 15°C to 1.67 kA/cm^2 at 75°C. The corresponding characteristic temperature T_0 for the threshold current density is 73°C, shown in the inset of Fig. 4. T_0 as high as 77°C and as low as 67°C were observed for lasers 2000x100 μm^2 and 1250x50 μm^2, respectively.

The position of the lasing wavelength as a function of heat sink temperature is shown in Fig. 5. From the slope we get the shift of the lasing wavelength with temperature ($\Delta\lambda/\Delta T$), which is found to be 3.1 Å/°C. This value compares favorably to $\Delta\lambda/\Delta T$ for GaInNAs lasers (4.8 Å/°C) [3]. A small value of $\Delta\lambda/\Delta T$ is important for VCSELs, since the temperature performance of VCSELs is strongly influenced by the difference between the temperature coefficients of the active region gain peak wavelength and the cavity resonance wavelength, and the Fabry-Perot mode of an AlGaAs/GaAs based VCSEL cavity shifts at only 0.6 Å/°C [10]. The gain peak of GaAs shifts at 3 Å/°C [10], a value similar to that of GaAsSb, indicating similar thermal performance can be expected from VCSELs incorporating these types of active regions.

We also measured internal quantum efficiency η_i and internal losses, α_i. These were obtained from a plot of inverse slope efficiency as a function of resonator length, shown in Fig. 6. η_i values of 38% and α_i of 5.5 cm^{-1} were found for a 75 μm wide laser (slightly lower values were found for a 100 μm wide laser). The somewhat low values of η_i can be attributed to the reduced overlap of the matrix element characteristic of the type II GaAs/GaAsSb band alignment as well as lack of electron confinement in the conduction band. Internal quantum efficiencies for type II GaAsSb/InGaAs laser structures matched to InP substrates have been found to be as low as 14% [6].

Fig. 7 shows the threshold modal gain as a function of a threshold current density, J_{th} for 75 μm and 100 μm wide lasers. Material gain can be obtained by dividing the modal gain by the confinement factor, Γ, which for this structure was calculated to be 0.01146. Thus at J_{th}=1 kA/cm^2, the material gain is 1710 cm^{-1} for a 75 μm wide laser. The gain constant G_0 and transparency current density J_{tr} were extracted from Fig. 7 in a manner described in [3]. G_0 was found to be 1660 cm^{-1} and J_{tr} was measured to be 134 A/cm^2 for a 75 μm wide laser. These values compare favorably to values for other materials capable of emission in this wavelength range, with the exception of GaInNAs [3].

In conclusion, we have described room temperature, pulsed operation of GaAsSb/GaAs based edge emitting lasers. These lasers emit at 1.27 μm with threshold current densities as low as 535 A/cm^2. We have measured, for the first time, T_0 for this material and found it to be as high as 77°C. We also found η_i of 38% and α_i of 5.5 cm^{-1}. Finally, we report a gain constant G_0 of 1660 cm^{-1} and a transparency current density J_{tr} of 134 A/cm^2. These parameters indicate that these materials may be promising candidates for 1.3 μm VCSEL active regions, if slightly longer wavelength operation can be obtained.

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Figure Captions

Fig. 1 Layer structure for the GaAsSb quantum well laser.

Fig. 2 Below- and above-threshold spectra of a 1250 μm long and 75 μm wide laser under room temperature pulsed operation (3μsec pulse, 10 kHz repetition rate).

Fig. 3 Peak output power per facet as a function of the drive current for a 2000 μm long and 100 μm wide laser, taken at room temperature under pulsed operation (0.5 μsec pulse, 10 kHz repetition rate).

Fig. 4 Peak output power per facet as a function of the drive current for a 1250 μm long and 75 μm wide laser, taken at a variety of heat sink temperatures under pulsed operation (0.5 μsec pulse, 10 kHz repetition rate). The inset shows the threshold current as a function of heat sink temperature

Fig. 5 Lasing wavelength as a function of heat sink temperature under pulsed operation (0.5 μsec pulse, 10 kHz repetition rate).

Fig. 6 Inverse slope efficiency as a function resonator length for a 75 μm wide laser.

Fig. 7 Modal gain at threshold as a function of a threshold current density for 75 μm and 100 μm wide laser stripes.

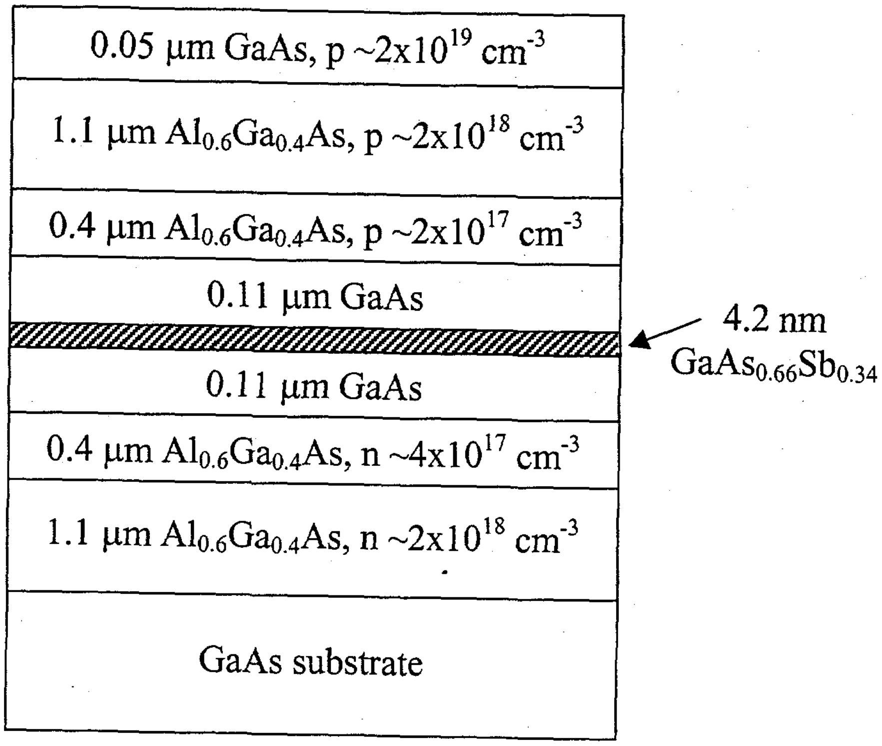

0.05 µm GaAs, p ~2×10^{19} cm^{-3}
1.1 µm $Al_{0.6}Ga_{0.4}As$, p ~2×10^{18} cm^{-3}
0.4 µm $Al_{0.6}Ga_{0.4}As$, p ~2×10^{17} cm^{-3}
0.11 µm GaAs
4.2 nm
$GaAs_{0.66}Sb_{0.34}$
0.11 µm GaAs
0.4 µm $Al_{0.6}Ga_{0.4}As$, n ~4×10^{17} cm^{-3}
1.1 µm $Al_{0.6}Ga_{0.4}As$, n ~2×10^{18} cm^{-3}
GaAs substrate

Fig. 1

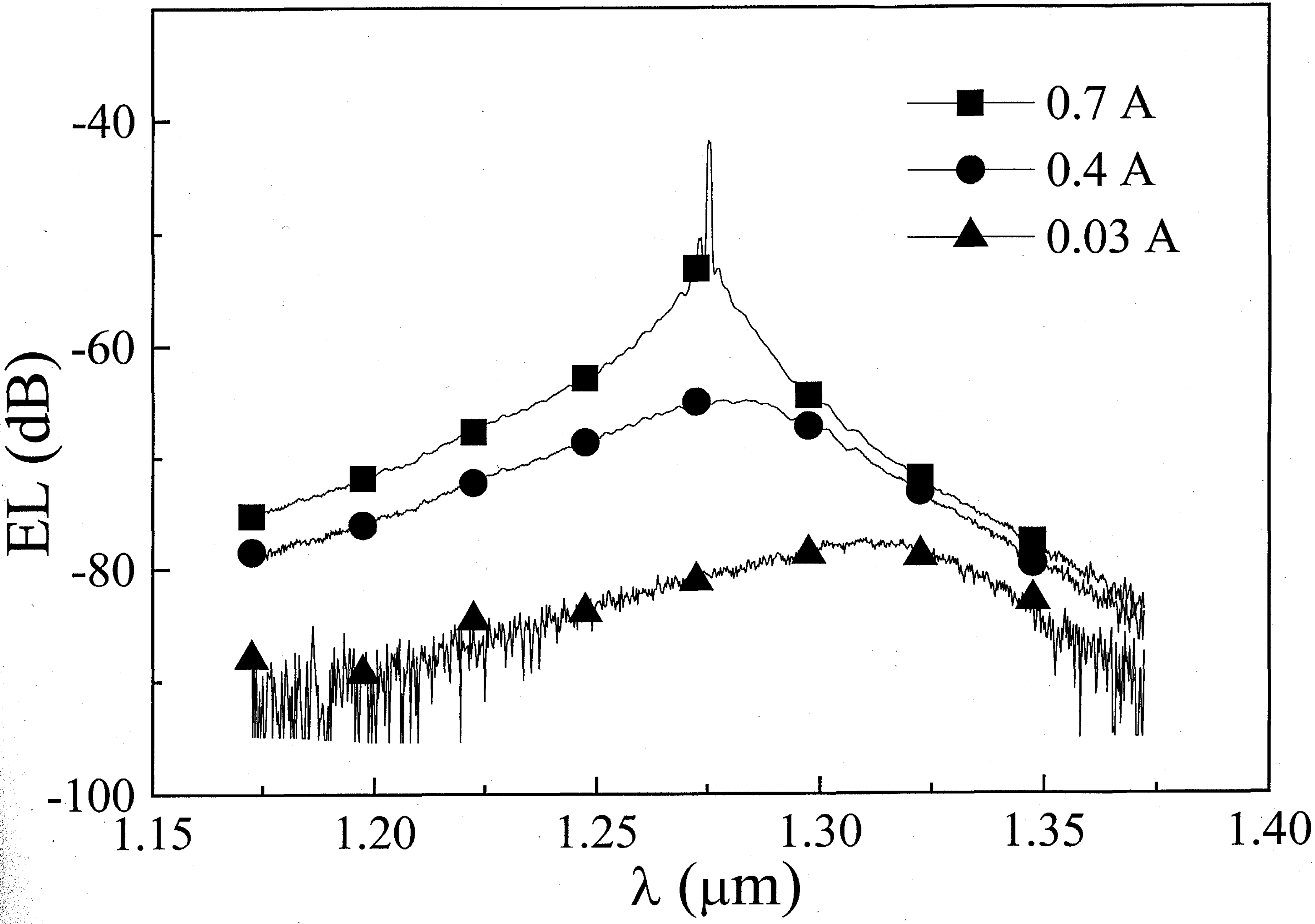


Fig. 2

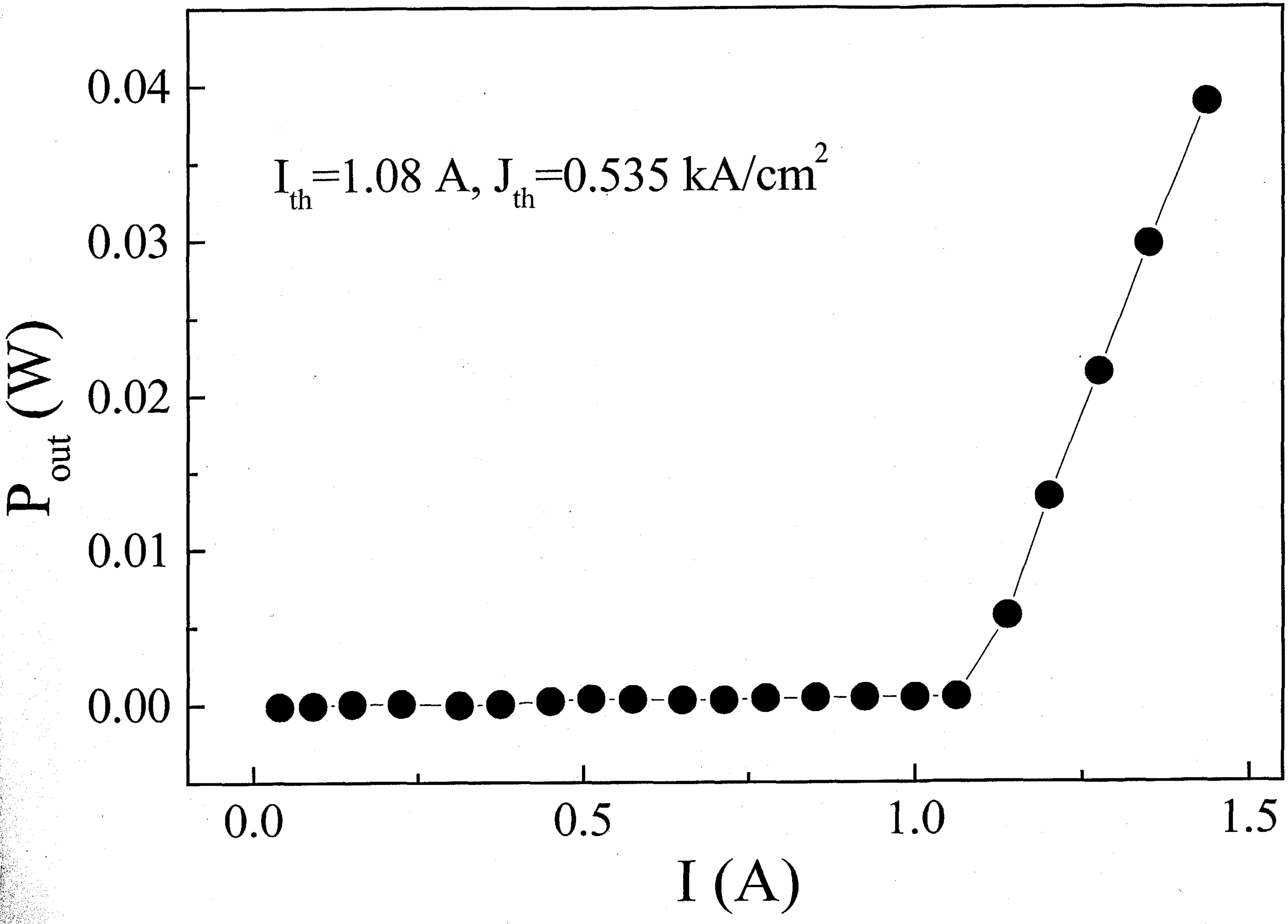


Fig. 3

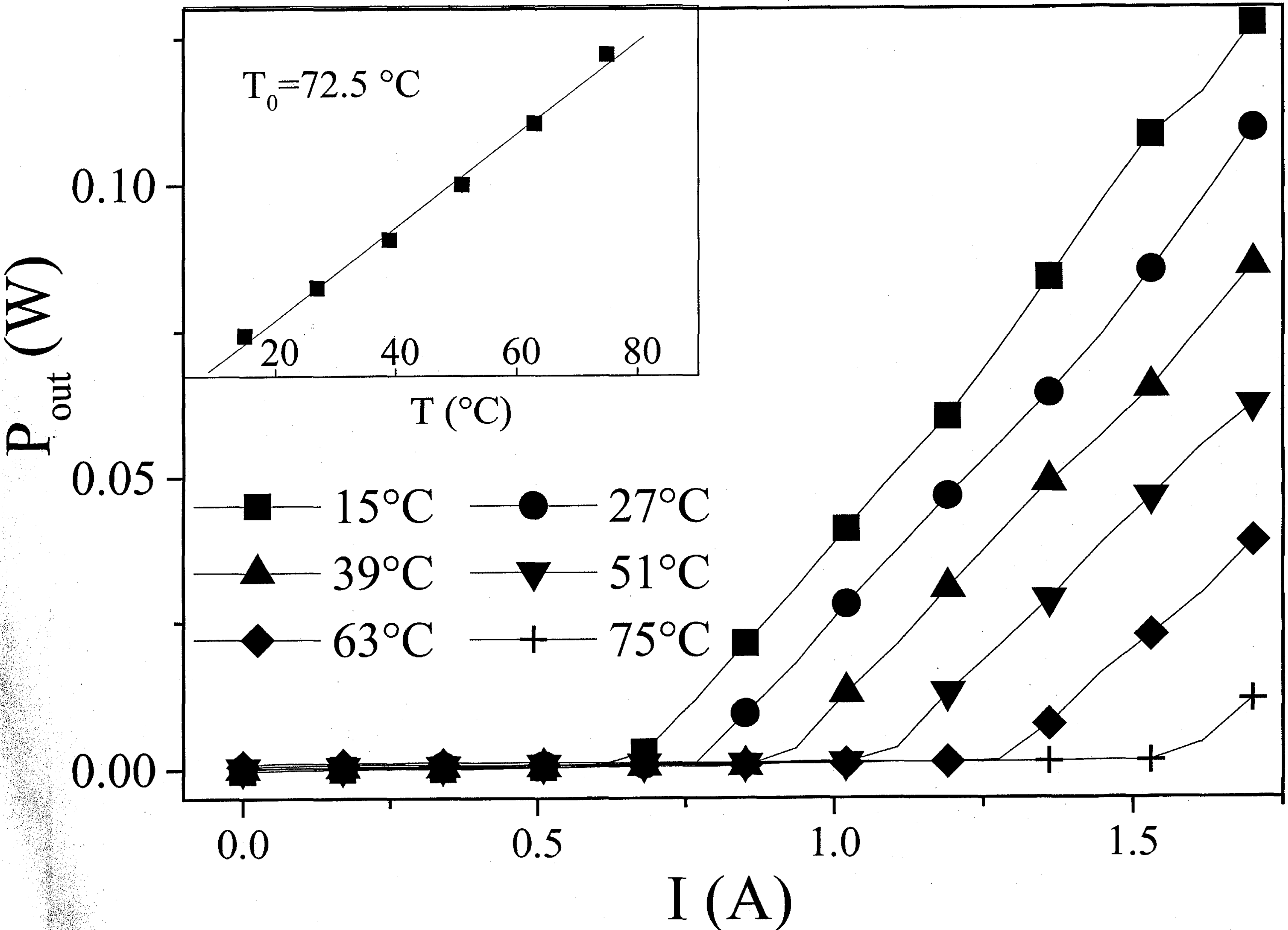
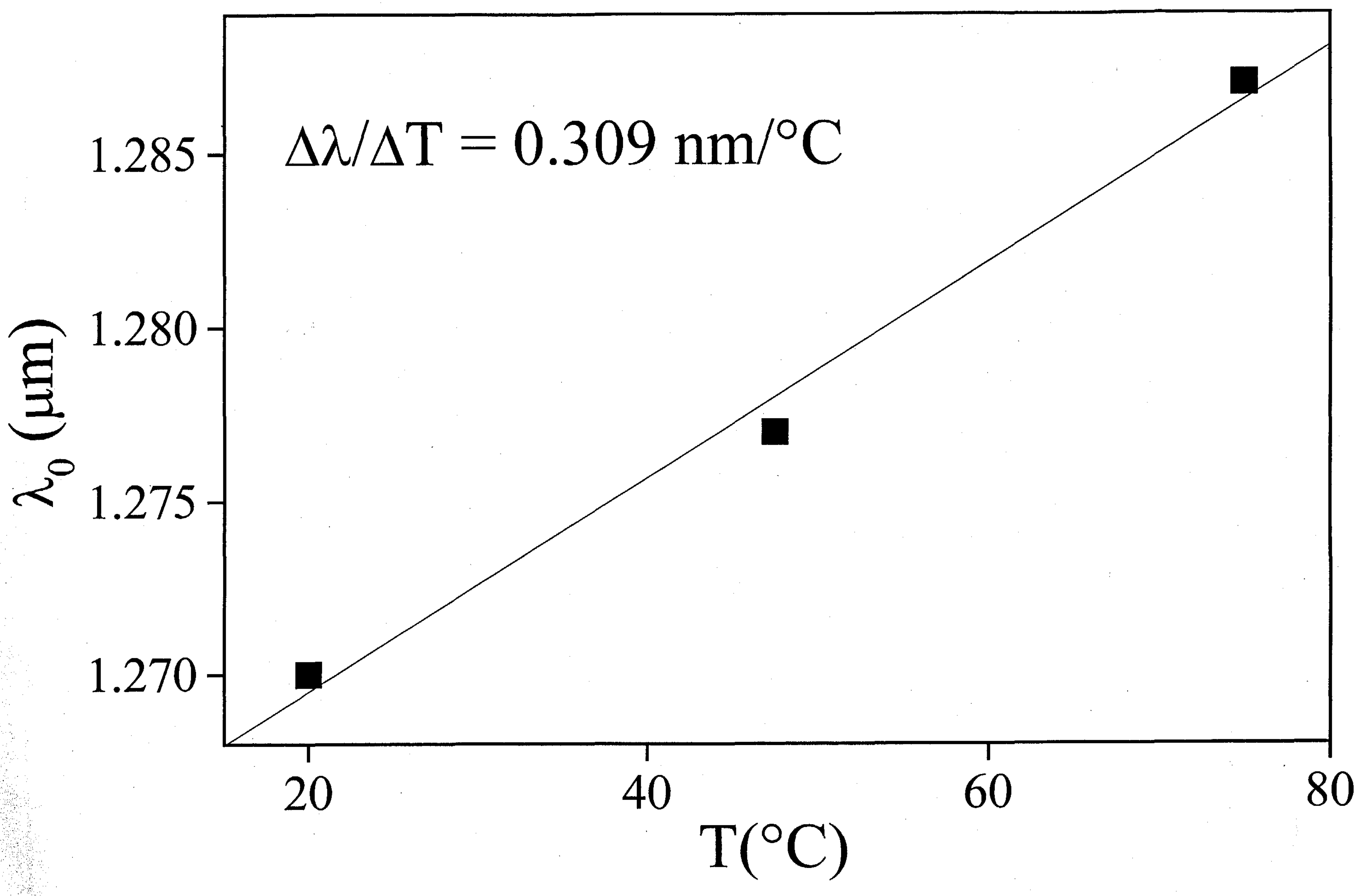
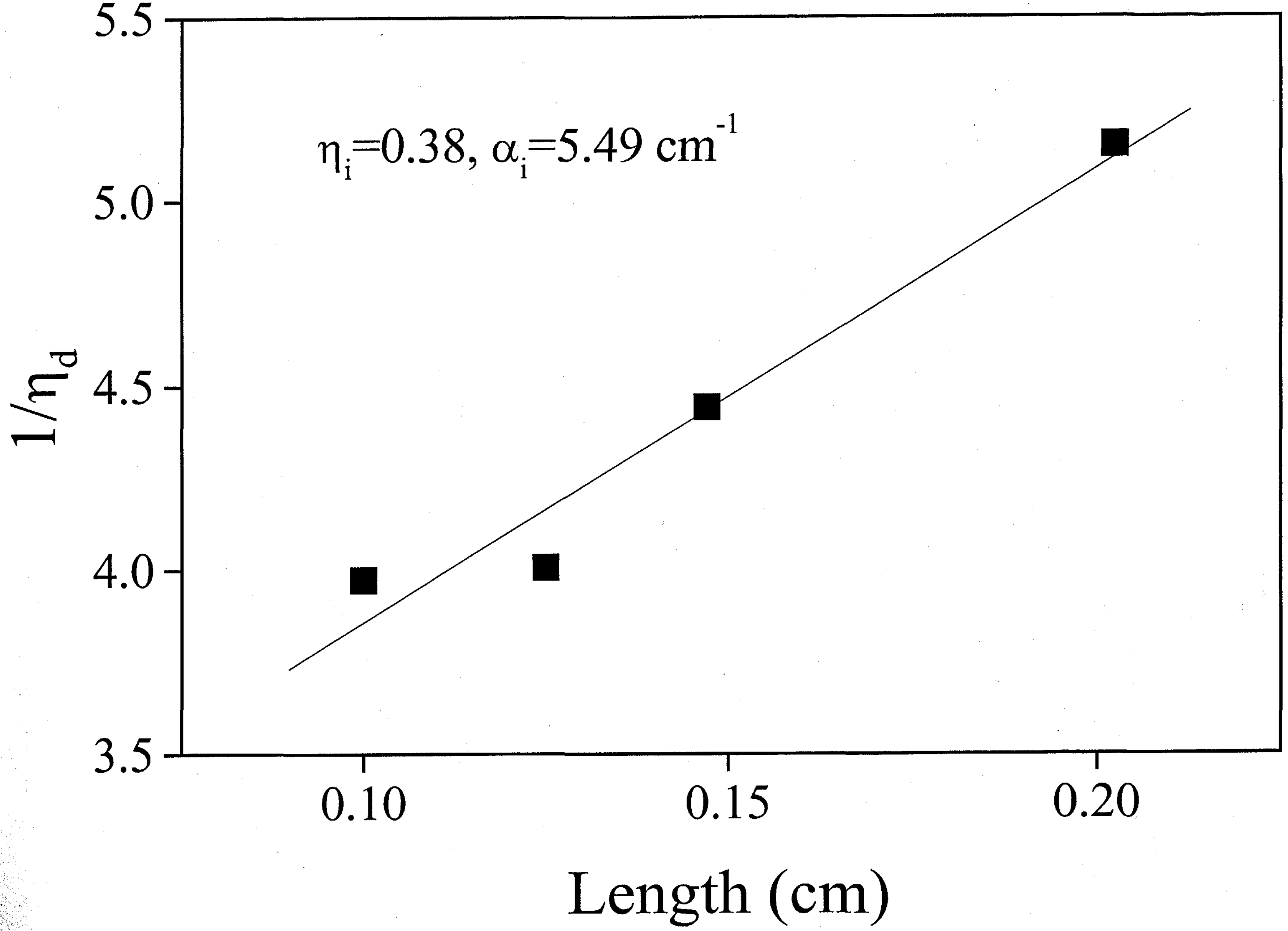

T$_0$=72.5 °C
20
40
60
80
T (°C)
15°C
27°C
39°C
51°C
63°C
75°C
P$_{out}$ (W)
0.00
0.05
0.10
0.0
0.5
1.0
1.5
I (A)

fig. 4


Δλ/ΔT = 0.309 nm/°C
λ0 (μm)
1.285
1.280
1.275
1.270
20
40
60
80
T(°C)


5.5
5.0
4.5
4.0
3.5
$1/\eta_d$
η_i=0.38, α_i=5.49 cm^{-1}
0.10
0.15
0.20
Length (cm)

g. 6

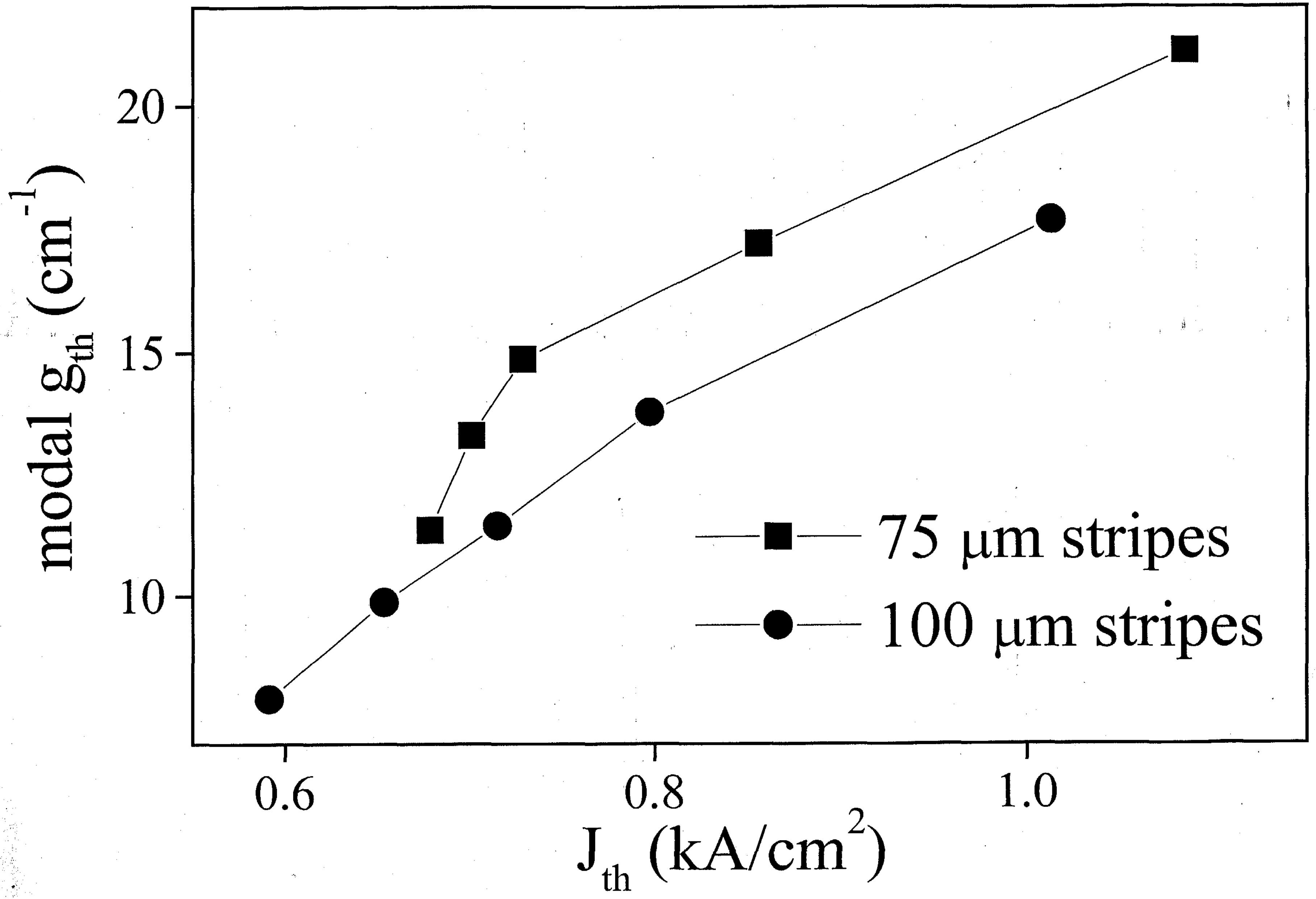

modal g_{th} (cm^{-1})
20
15
10
0.6
0.8
1.0
J_{th} (kA/cm^2)
75 µm stripes
100 µm stripes

Fig 7