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Rare-earth doped chalcogenide glass laser

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Abstract

Laser action in a rare-earth doped chalcogenide glass was demonstrated for the first time showing that this class of glasses is suitable for active applications such as optical amplifiers and lasers. The neodymium-doped gallium lanthanum sulphide glass laser operated continuous wave at a wavelength of 1.08 µm when pumped with a Ti:sapphire laser at either 0.815 µm or 0.890 µm.

Introduction: The family of the chalcogenide glasses has been studied extensively due to their interesting optical, electrical and acoustic properties [1]. The main optical features of chalcogenide glasses compared to the common silica glasses are their transparency at long wavelengths and their low non-radiative decay rates of rare-earth energy levels both of which result from the low vibrational frequencies of the glass bonds. Together with an increase in the radiative decay rate of these energy levels due to the high refractive index of the chalcogenides, these glass properties open up new transitions and increase the quantum efficiency of existing transitions between rare-earth energy levels compared to silica and fluoride glasses [2-4]. However, to our knowledge, laser action in rare-earth doped chalcogenide glasses has not been demonstrated to date.

Neodymium-doped gallium lanthanum sulphide glass (Ga:La:S) was proposed as a laser material earlier by Bornstein et al. and Flahaut et al. [5,6]. Calculations of the laser threshold for side-pumping showed a lower value for Ga:La:S glass than for other glasses and YAG crystals, however laser action could not be achieved.

In this paper we present spectroscopy and the first laser experiments on neodymium-doped Ga:La:S glass.

Experiments and results: A Nd^{3+}-doped Ga:La:S glass was prepared by mixing Ga_2S_3, La_2S_3, and Nd_2S_3 powders with the molar ratio of 70:28.5:1.5, melting at 1150°C for eight hours, and quenching the melt to room temperature.

Absorption measurements in the visible and near-infrared spectral region were performed with an Perkin Elmer Lambda 9 spectrophotometer. The mid-infrared absorption was measured with a Fourier Transform Spectrometer (Perkin Elmer System 2000 FT-IR). Figure 1 shows the ground state absorption spectrum of a 1.42 mm thick sample in the whole spectral range. The spectrum shows the wide transmission range of the glass starting at the UV absorption edge at 0.5 μm and extending beyond 8 μm. This allows the measurement of the absorption into the $^4I_{11/2}$ level at 5.2 μm. The absorption bands of the $^2H_{9/2}$ and $^4F_{5/2}$ levels and the upper laser level $^4F_{3/2}$ at 0.815 μm and 0.890 μm, respectively, were used to pump the $^4F_{3/2} \rightarrow ^4I_{11/2}$ laser transition. The absorption coefficient of the $^2H_{9/2}$ and $^4F_{5/2}$ levels is three times larger than the absorption coefficient of the $^4F_{3/2}$ level leading to absorption lengths of 0.7 mm and 2.0 mm, respectively.

For fluorescence measurements the Nd^{3+}-ions were excited into the $^2H_{9/2}$,$^4F_{5/2}$ levels using a Ti:sapphire laser operating at 0.815 μm. Multiphonon decay from the $^2H_{9/2}$,$^4F_{5/2}$ levels populates the $^4F_{3/2}$ level which has a decay time of 70 μs. Three fluorescence transitions have been measured with an ANDO spectrum analyser. They are shown in figure 2 together with the pump laser spectrum. Laser action on each of these transitions has been reported in many host materials. In this work laser operation could only be obtained on the strongest transition at 1.08 μm.

A simple hemispherical resonator consisting of a plane input coupler having high reflectivity at 1.08 μm and various output couplers with 50 mm radius of curvature were used for the laser experiments. The glass sample was placed close to the plane input mirror. A 50 mm focal length lens focussed the Ti:sapphire pump beam into the glass sample. The output power was measured with a pyroelectric powermeter using suitable filters to block the unabsorbed Ti:sapphire radiation.

Laser action could be achieved with a 1.42 mm thick sample of Ga:La:S glass doped with 1.5mol% (2.6×10^{20} ions/cm^3) neodymium for pump wavelengths of 0.815 μm and 0.890 μm. The laser spectrum extended from 1.073 μm to 1.087 μm with a maximum at 1.08 μm. Better laser results could be obtained with the longer pump wavelength that directly excites the upper laser level without generating heat through the multiphonon decay from the $^2H_{9/2}$,$^4F_{5/2}$ levels to the upper laser level $^4F_{3/2}$. The smaller absorption coefficient at 0.890 μm also reduces the thermal load on the glass and leads to a more homogeneous excitation of the sample. At a pump wavelength of 0.815 μm 88% of the pump power is absorbed while at a pump wavelength of 0.890 μm only 50% is absorbed. The dependence of the output power on the absorbed pump power in figure 3 clearly shows the thermal problems of the glass. Laser action ceases at high pump powers. These problems are expected due to the high coefficient of thermal expansion and the strong change of the refractive index with temperature dn/dT in chalcogenide glasses [1]. The two effects lead to strong thermal lensing that was observed directly by superimposing a red He/Ne laser beam on the infrared Ti:sapphire beam. When the Ti:sapphire was tuned to a neodymium absorption band the glass acted as a strong lens for the red He/Ne laser beam. The two input-output curves with 1% and 5% output coupling, respectively, show a minimum threshold of less than 10 mW, a maximum output power of 2.7 mW and a maximum slope efficiency η of 11%. The slope efficiency was fitted to the linear part at the beginning of each curve. Laser action could be achieved with an output coupling of up to 10%.

Conclusion: In conclusion we have demonstrated the first rare-earth doped chalcogenide glass laser. A Nd-doped Ga:La:S glass showed cw laser action at room temperature at a wavelength of 1.08 μm. The reasonably low laser threshold indicates acceptable glass losses but this preliminary laser performance is worse in comparison with conventional Nd-lasers. Improvements will be made by optimizing the doping concentration and the length of the sample. The results are a first step towards the realisation of fibre lasers operating at new wavelengths and 1.3 μm amplifiers for telecommunication based on Ga:La:S glass fibres, progress is also supported by recent results in Ga:La:S glass fibre fabrication [7].

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Figure captions

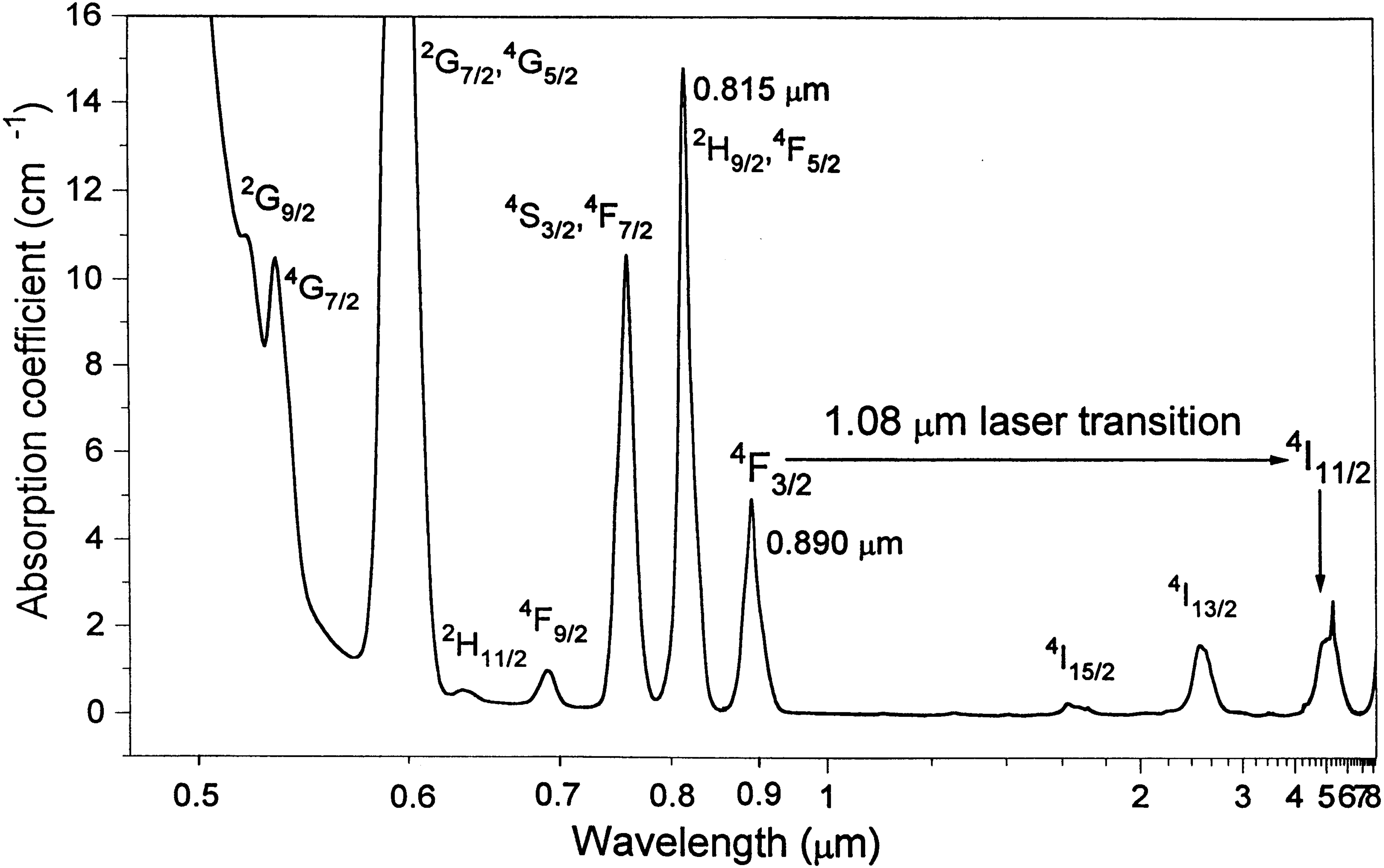
Figure 1 Room temperature ground state absorption spectrum of 1.42 mm thick 1.5mol% Nd-doped Ga:La:S glass with reciprocal wavelength scale

Figure 2 Room temperature fluorescence spectrum of Nd-doped Ga:La:S glass

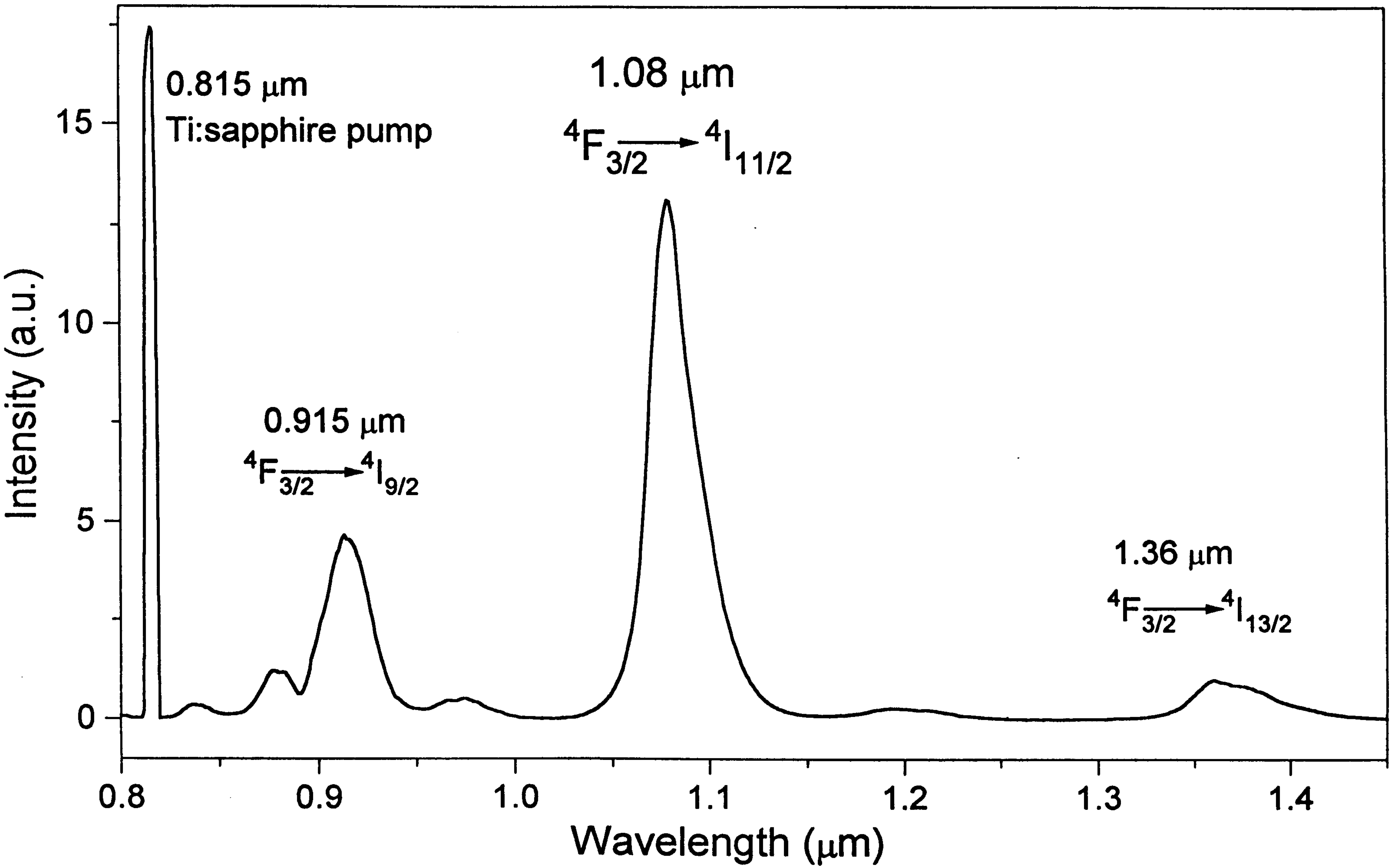
Figure 3 Output power versus absorbed pump power of the 1.08 μm Nd-doped Ga:La:S glass laser pumped at 0.890 μm

■: 1% output coupling, 4% slope efficiency

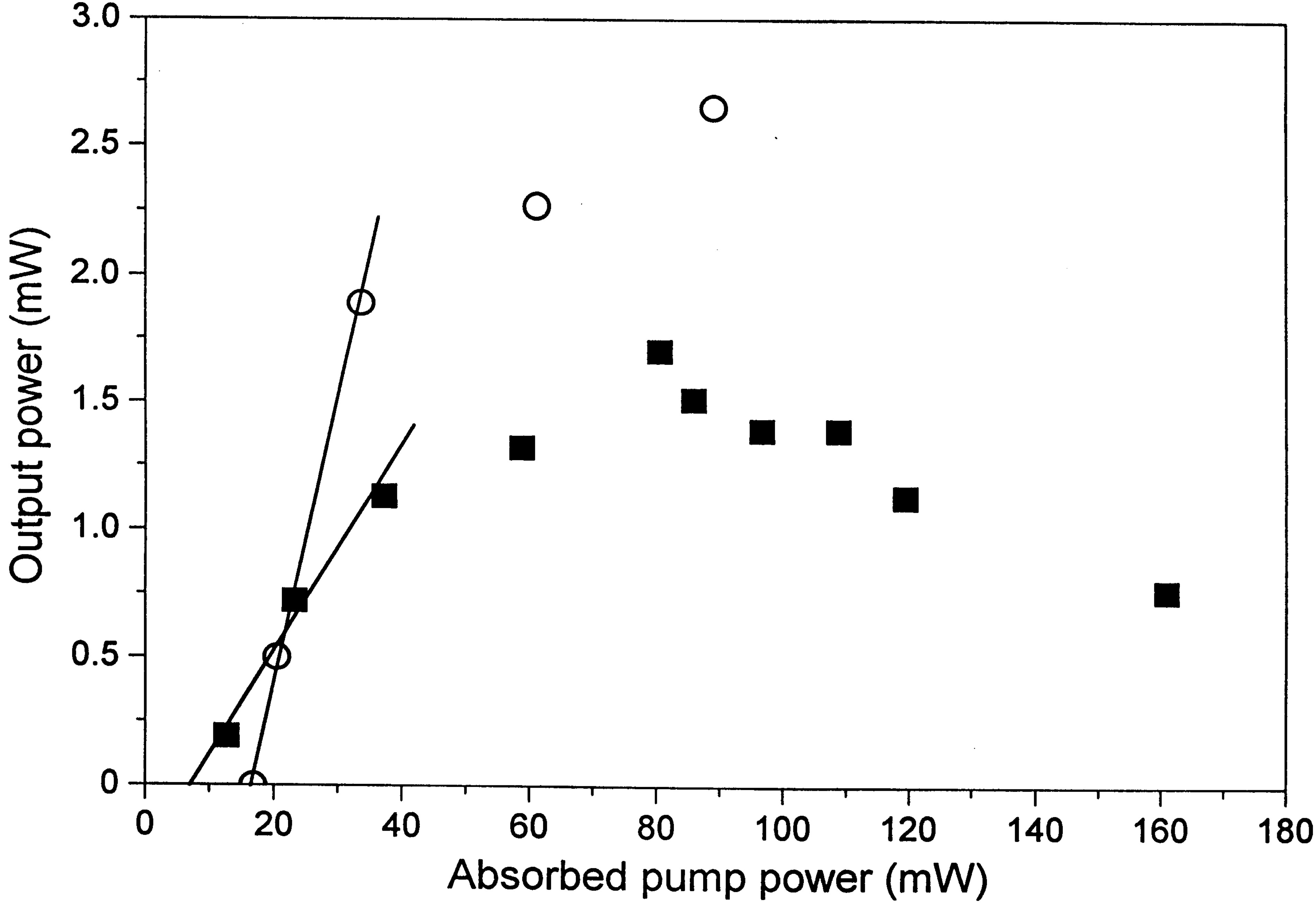
O: 5% output coupling, 11% slope efficiency



Absorption coefficient (cm -1)
16
14
12
10
8
6
4
2
0
0.5
0.6
0.7
0.8
0.9
1
2
3
4 5678
Wavelength (μm)
2G9/2
4G7/2
2G7/2, 4G5/2
2H11/2
4F9/2
4S3/2, 4F7/2
0.815 μm
2H9/2, 4F5/2
4F3/2
0.890 μm
1.08 μm laser transition
4I11/2
4I15/2
4I13/2



0.815 μm
Ti:sapphire pump
1.08 μm
4F3/2 → 4I11/2
0.915 μm
4F3/2 → 4I9/2
1.36 μm
4F3/2 → 4I13/2
Intensity (a.u.)
15
10
5
0
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Wavelength (μm)


3.0
2.5
2.0
1.5
1.0
0.5
0
Output power (mW)
0
20
40
60
80
100
120
140
160
180
Absorbed pump power (mW)