232

O.F.C. Atlanta 1986.

Rare-Earth-Doped Fibre Lasers

R.J.Mears, L.Reekie, S.B.Poole, D.N.Payne
Department of Electronics and Information Engineering
The University, Southampton, SO9 5NH, England
Tel. (0703) 559122

Abstract

Fabrication and absorption/fluorescence properties of several rare-earth-doped fibres are reported. A 7.4 m long Er^{3+} fibre laser emitting at wavelength of 1.536 μm has been constructed.

Rare-Earth-Doped Fibre Lasers

R.J.Mears, L.Reekie, S.B.Poole, D.N.Payne

Department of Electronics and Information Engineering

The University, Southampton, SO9 5NH, England

Tel. (0703) 559122

By virtue of their broad fluorescence linewidth, rare-earth-doped single-mode fibre lasers could allow the construction of tunable sources and broadband optical amplifiers for wavelength-division multiplexing and long-distance optical communications systems. Similarly, doped-fibre amplifiers could also provide a means of overcoming soliton propagation losses. We describe here the fabrication and characteristics of several new rare-earth-doped optical fibres, fabricated using an extension of the MCVD technique[1]. The fibres are unique in combining very-high-loss absorption bands in the visible and near infra-red regions (e.g. >9000 dB/km for Er^{3+}), but with losses comparable to telecommunications-type fibres (<2 dB/km) in the 1300nm region. This attribute has for the first time allowed long lengths of single-mode fibre to be used in both Fabry-Perot and ring laser configurations[2]. As well as Nd^{3+} lasers operating at 1.08 μm, we now report the first Er^{3+} fibre laser. The laser operates at coinciding with the important 3rd telecommunications window.

The fabrication technique has been described previously[1]. An additional upstream dopant carrier-chamber containing solid rare-earth halides is incorporated in the MCVD tube and heated during core deposition. A chlorine drying stage purifies the unfused deposited layer so as to give fibre losses similar to conventional single-mode fibres. The technique has been used to produce single- and multi-mode fibres containing a variety of rare-earths as well as highly-birefringent "Bow-Tie" fibres.

Log-loss curves for fibres doped with Nd^{3+}, Er^{3+} and Tb^{3+} ions are shown in Fig.1. These illustrate the very sharp high-loss absorption bands present in the visible/near infra-red region, closely flanked by low-loss windows similar to those in undoped fibres. For example,the Er^{3+}-doped fibre has a 9000 dB/km absorption band at 520 nm and a 10 dB/km window only 40 nm away at 560 nm. The low OH^- absorptions at 1390 nm indicate the success of the two-stage drying technique used.The fluorescence spectra for these fibres, indicating the wavelengths at which lasing is likely to occur, are given in Fig.2. These are similar to spectra previously reported for rare-earth ions in compound glasses, but have their fluorescence peaks shifted to longer wavelengths owing to the silica host. OTDR measurements of the dopant incorporation along the fibre length show good uniformity.

Using an 850 nm semiconductor-laser end pump, laser action (1.08 μm) at a threshold of only 0.6 mW has been observed in Nd^{3+}-doped fibres[2]. Feedback was provided by two dielectric-coated mirrors butt-coupled to give a high-finesse cavity. The lasing characteristic and the output spectrum is given in Fig (3). Using a 590 nm dye-laser-pump and a ring configuration made by splicing together the two arms of an Nd^{3+}-doped fused-taper coupler, an output power of several mW around 1.08 μm was obtained with a slope efficiency of 20%. The wavelength could be tuned by varying the coupler characteristics.

An Er^{3+}-fibre laser was constructed using 7.4 m of the fibre whose properties are shown in Figs.(1) and (2). Mirrors transparent to the 514 nm Argon-ion pump but with 5% transmission at the lasing wavelength were butt-coupled to the fibre to form a Fabry-Perot cavity. Laser action was observed at the peak of the 3-level $^4I_{13/2}$ - $^4I_{15/2}$ fluorescence band, i.e. λ= 1.536 μm, which is very close to the minimum loss wavelength in silica fibres. Owing to the small core diameter (5 μm), saturation of the absorption at λ= 1.536 um is easily achieved with only a few mW of pump power, allowing an unprecedented low threshold for a 3-level laser. The lasing characteristic and output spectrum for this laser are shown in Fig.(3). Note that although the threshold is shown at a pump level of 20 mW, this corresponds to only 4 mW of absorbed power, indicating the potential for much lower thresholds. With non-optimal output coupling, the output power was found to be several tens of μW. This result simultaneously represents the first report of an Er^{3+} fibre laser, the longest fibre laser yet achieved and, to our knowledge, the only report of a CW Er^{3+} laser in glass.

Detailed results will be presented on the spectral and temporal output characteristics of rare-earth-doped fibre lasers, along with an analysis of pump requirements needed to develop practical sources.

References

1) Poole,S.B.,Payne,D.N.,Fermann,M.E., Electron.Lett., 21, 1985, pp 737-738.

2) Mears,R.J.,Reekie,l.,Poole,S.B.,Payne,D.N., ibid., pp 738-740.

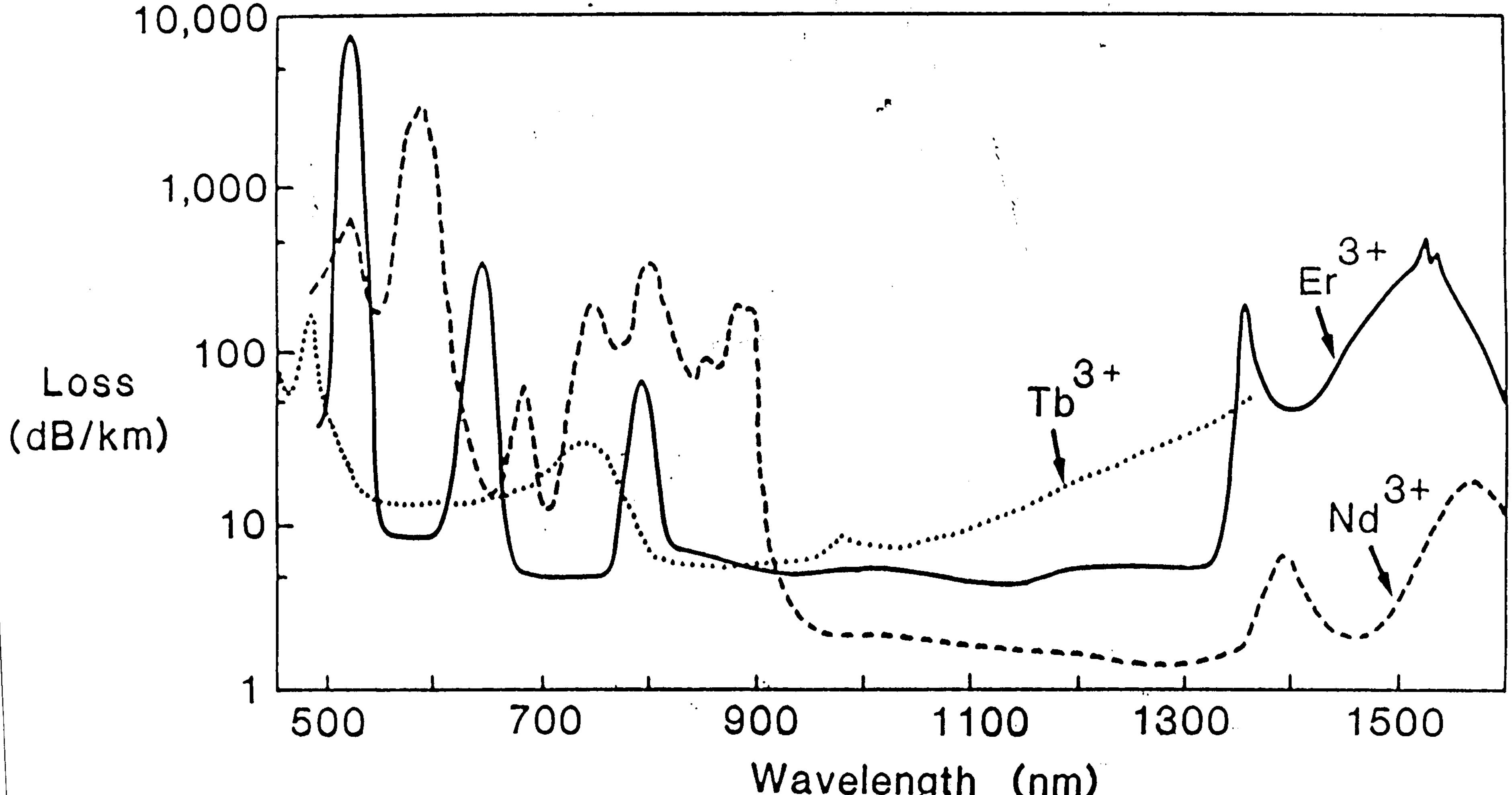
"Laser fibres" Mears et.al.

Figure Captions

Fig.1 Log-loss spectra for single-mode fibres doped with rare-earths. Note low-loss windows despite very high absorption bands.

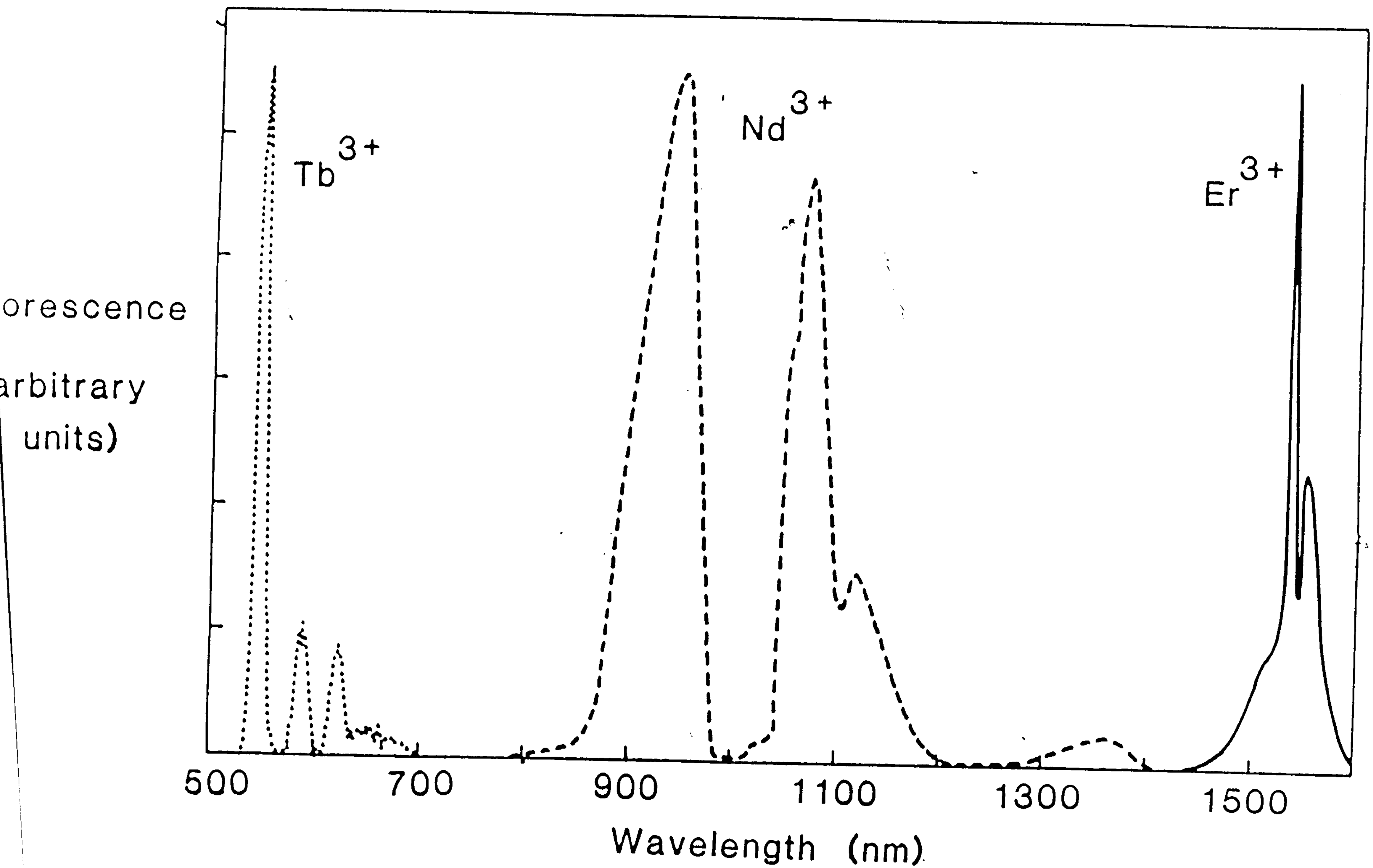
Fig.2 Rare-earth doped fibre fluorescence spectra.

Fig.3 Lasing characteristics and output spectra for Nd^{3+} and Er^{3+} single-mode fibre lasers.

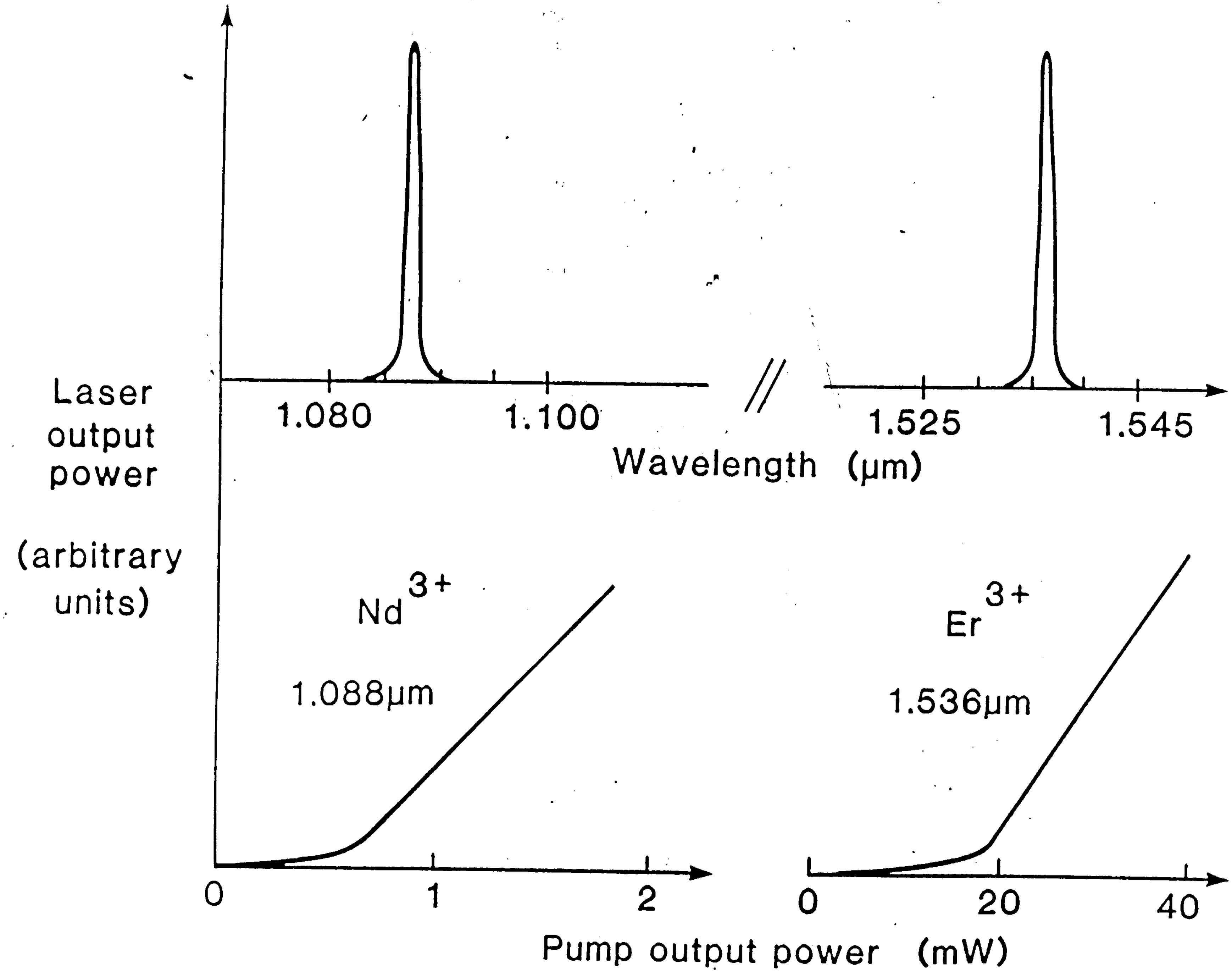


Loss (dB/km)
10,000
1,000
100
10
1
500
700
900
1100
1300
1500
Wavelength (nm)
Er^{3+}
Tb^{3+}
Nd^{3+}

1 MEARS et al


Tb3+
Nd3+
Er3+
oresscence
arbitrary
units)
500
700
900
1100
1300
1500
Wavelength (nm)

Mears et al


Laser output power
(arbitrary units)
1.080
1.100
1.525
1.545
Wavelength (μm)
Nd 3+
1.088μm
Er 3+
1.536μm
0
1
2
0
20
40
Pump output power (mW)