Application of powerful QW InGaAs/GaAs laser as excitation source for TR^{3+} -doped fluoride and telluride fiber lasers and amplifiers

A.A.Andronov, I.A.Grishin, V.A.Guryev, and A.P.Savikin*)

Nizhni Novgorod State University, 23 Gagarin Avenue,
Nizhni Novgorod 603950, Russia

B.N.Zvonkov

Physical–Technical Research Institute, University of Nizhni Novgorod,
23/3 Gagarin Avenue, Nizhni Novgorod 603950, Russia

We report an application of powerful QW *InGaAs/GaAs* laser diode as excitation source for TR^{3+} -doped fluoride and tellurite glasses. It has been shown that some disadvantages inherent to laser diodes can be compensated by proper use of optical fiber technology. The role of interionic energy transfer in application of powerful laser diodes to active fiber–optics is discussed.

1. *Introduction*

It was investigated last decades that heavy-metal multicomponent glasses doped with various trivalent Rare-Earth ions have many advantages in comparison with silica for developing active components of optical telecommunications such as fiber master-oscillators (lasers) and fiber amplifiers [1]. Glasses are also chemically stable and may contain much greater amount of TR^{3+} content (up to 7 mol.% for fluoride and up to 25 mol.% for telluride) in comparison with silica (less than 0.7 mol.%). These glasses extended IR-transmission band (up to 5 μm) and strong inhomogeneous broadening that makes optical absorption and emission lines, which correspond to transitions between terms of optically active *4f* shield of TR^{3+} ions, wider and smoother. Moreover, due to low multiphonon relaxation rate [3], caused by low phonon energies, ~500 cm^{-1} and 850 cm^{-1} for fluoride and tellurite glasses, correspondingly, radiative lifetimes of most TR^{3+} manifolds in mentioned glasses sufficiently increase in comparison with silica. The phenomenon of efficient stepwise upconversion fluorescence from Erbium (*Er*), Thulium (*Tm*), Holmium (*Ho*) and some other TR^{3+} ions is also inherent to mentioned multicomponent glasses.

There are many excitation sources used for optical excitation of TR^{3+} ions in those glasses, for instance: Ar^{+} ion laser, Nd^{3+}:YAG (with frequency doubling), some tunable dye-lasers, IR diode-lasers of various wavelengths. In present work we have demonstrated that only efficient diode-lasers are practically valuable for optical excitation of TR^{3+} in novel optical glasses.

*) Phone: +7-8312-656152, Fax: +7-8312-656416, E-mail: savikin@rf.unn.runnet.ru
URL: http://quantum.h1.ru

2. *Experimental results and discussion*

As a principal excitation source for TR^{3+} ions in fluorozirconate and telluride glasses a powerful *InGaAs/GaAs* quantum-well laser diode (QW LD), [2], has been chosen. Several samples of such lasers have been kindly provided for our research with Epitaxial Technology Group of Physical-Technical Research Institute (PTRI) of UNN, Head – Dr. B.N.Zvonkov.

Quantum-well lasers have regular CW output power higher than 1 W at wavelengths lying in band 970…985 nm. The lasing typically has a bandwidth $\delta\lambda_{LAS}$ about of 2 nm. The exact wavelength can be tuned by temperature of diode crystal with tuning ratio about of 1 nm/^{0}C by using controlled Peltier cell. The QW heterostructure is very efficient – the efficiency value of given chips is near 65 %. Nevertheless, QW LD has several disadvantages, which make this kind of lasers inapplicable as master-oscillators for optical telecommunications:

- The laser wavelength (λ_{LAS}) is far away from telecommunication windows – 0.8 μm, 1.33 μm, 1.54 μm. The maximum λ_{LAS} for QW structures is about of 1.03 μm.
- The divergency of QW LD beam is very high – more than 50^0. It means, that coupling of this radiation into the telecommunication optical fiber (even multimode) will be extremely low efficient.
- The mentioned strong temperature dependence of λ_{LAS} is very poor feature for an optical master-oscillator. It has to be notified, however, that such dependence is inherent for any types of laser diodes.
- Studied laser diodes have a rich set of transversal modes in lasing. They have different Q-values, hence, the different threshold currents; moreover, values of λ_{LAS} and output power may sufficiently vary within each mode.

Despite of these facts, QW LD from PTRI UNN are very attractive as optical excitation source of TR^{3+} ions in studied fluoride and telluride glasses.

Let's stipulate some statements.

- There are many TR^{3+} ions have ground-state absorption (GSA) bands near 0.98 μm and up to 1.02 μm: Ytterbium (*Yb^{3+}*) – transition $^2F_{7/2} \rightarrow {}^2F_{5/2}$ (λ_{ABS} = 0.975 μm); Erbium (Er^{3+}), $^4I_{15/2} \rightarrow {}^4I_{11/2}$ (λ_{ABS} = 0.98 μm); Dysprosium (Dy^{3+}), $^6H_{15/2} \rightarrow {}^6H_{5/2}$ (λ_{ABS} = 0.96 μm); Praseodymium (Pr^{3+}), $^3H_4 \rightarrow {}^1G_4$ (λ_{ABS} = 1.017 μm). These ions have provided luminescence and amplification at various bands of IR, also inside a most of telecommunication windows.
- Due to strong inhomogeneous broadening pump efficiency show no sense to temperature variations of LD wavelength. Vice versa, temperature-tuning ability is even useful for better matching with a GSA peak. High value of $\delta\lambda_{LAS}$ is also not a problem for TR^{3+}-in-glass excitation – typical width of GSA peaks here is about 7…15 nm (compared with one in crystals about 0.2…0.8 nm).
- There is a rather new and very promising technique in active fiber–optics that can avoid a problem with a high degree of LD divergency – "cladding pumping". The principal idea of cladding pumping is shown in Fig. 1.

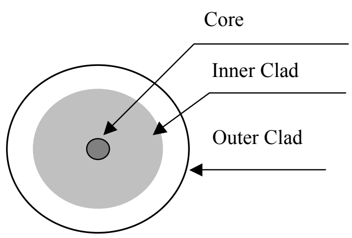

Fig. 1.

A single-mode core, doped with active TR^{3+} ions such as Er^{3+} or Pr^{3+}, has a small diameter ~2…5 µm. An inner clad has the same refractive index n_{CORE} but its diameter is much higher, about of 50…100 µm. It can be doped with "donor-type" ion – Yb^{3+}. An undoped, mechanically protected outer clad has less refractive index n_{CLAD}, and standard diameter 125 µm. Thus, the numerical aperture (NA) $NA = \sqrt{n_{CORE}^2 - n_{CLAD}^2}$ of this system is high enough to launch a divergent LD beam into the fiber, although its core is single-mode. Energy transfer from inner clad into the core causes the profit of this system.

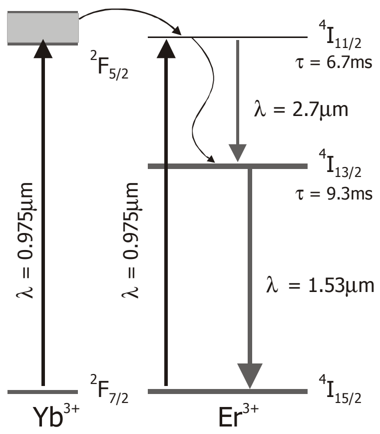

Fig. 2.

The nature of such transfer is rather complex. The best example of it the mentioned above pair Erbium (core doping) and Ytterbium (inner clad doping) shows. Ytterbium ion effectively absorbs radiation of QW LD at λ=0.975 µm and transfers this energy to the nearest manifold of Erbium, $^4I_{11/2}$, via cross-relaxation (generally, phonon-assisted) as shown in Fig. 2. After the phonon-assisted relaxation Er^{3+} ions have been accumulated onto the $^4I_{13/2}$ level that provides 1.53 µm emission after termination into the ground state.

This work was supported by grants of Russian CCFNS Foundation No. E00-3.4-312, and NATO SfP–973799 Semiconductors.

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