Waveguide amplifiers in rare-earth doped glasses: fabrication, characterisation [MATH] modelling
B. Hyde, D. Barbier, J. Hubner, J.-M. Jouanno, A. Kevorkian, A. Lupascu

To cite this version:

HAL Id: jpa-00252731
https://hal.archives-ouvertes.fr/jpa-00252731
Submitted on 1 Jan 1994

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Waveguide amplifiers in rare-earth doped glasses: fabrication, characterisation & modelling


AlpOptics, Le Pey, 38220 Laffrey, France
* GeeO, 46 Avenue Felix Viallet, 38031 Grenoble cedex, France
** Physics Dept., Uni. Polytechnica, Bucharest, Romania

Introduction.
Given a flexible integrated optical technology, one has access to a range of solutions to the problems of active devices on a single substrate, compared to say, a series of discrete fibre components strung together. The environmental advantages of a buried integrated structure compared to those made from discrete fibres is evident, although an optical fibre will often be the preferred input and output path and therefore fibre to guide compatibility is essential.

We have therefore adapted our ion-exchange technology to rare-earth doped glasses, with the intention of providing an active component on a chip.

Waveguide fabrication and Application.
Buried channel waveguides may be made by a two-step ionic exchange process in glass.

The exchange of suitable metallic ions between the glass and a molten salt produces a change in refractive index. If this is localised it will form a narrow region of a higher refractive index in the glass; that is, a channel waveguide. Examples of passive devices which are made by this process, are optical couplers splitters and tapers.

In addition the phase change of the passive directional coupler may be exploited in integrated devices to provide ‘loop mirrors’. Spatial gratings may be induced acousto-optically or exchanged into the glass to make Bragg type reflectors.

To achieve an active device we can pump or invert a rare-earth doped glass and use a spectral transition to provide gain and also a phase shift.

Such properties may be used to make laser amplifiers & oscillators, fluorescent sources, modulators & switches. These devices are feasible due to the small effective diameter of the guides and the consequent high optical intensities in a guide, and also due to the availability of pump laser diodes of high power.
Waveguide characterization.
We have made graded index waveguides in neodymium doped glasses and found those glasses which are the most suitable for our ionic exchange process.

Typically, a chip containing several guides is cut and both ends of the waveguide polished. For the experiment described here we made a buried waveguide, 38 mm in length and 10 μm in diameter.

In order to characterize this waveguide, we irradiated it with a pigtailed laser diode and observed the near-field intensity at the output with a CCD camera. At least 2 modes are guided at 785 nm. At this wavelength the size of the intensity profile of the fundamental mode is 3.8 μm in the transversal direction and 3.2 μm in the lateral one. The guide depth below the surface is 5 μm.

Amplifier characterization.
The neodymium doped guide was pumped with a laser diode at 812 nm. The maximum power absorbed was 35 mw. There are three major transitions observed, 900nm, 1055nm and 1325 nm. The transition at 900 nm is a 3-level transition and is partially re-absorbed. The 1055nm and 1325 nm transitions are 4-level.

We have measured the internal gain (2.7dB at 1.325μm and the amplified spontaneous emission of this structure and compared them with our model of the system. The guide propagation losses (0.3dB/cm) have also been measured using an 8 turn, 70 cm. coiled guide made by ion-exchange in the doped material.

System Modelling.
One important facet of our study is numerical modelling of an amplifier. This includes diffusion calculations for the technology and the spectroscopic, electromagnetic and opto-geometric calculations necessary to arrive at the output properties and predictions.

In order to build up the propagation equations, one requires the cross-sections and the fluorescent lifetime determined from fundamental measurements on the glass. This data has been derived from our spectroscopic and temporal measurements.

By solving the coupled differential equations of propagation we have access to a range of information on the expected performance of an optical amplifier.

Results.
The results are presented in graphical form below.
In fig.1 we see the evolution of the amplified spontaneous emission (ASE) with pump power. Clearly the ASE at 1.055 μm is the most important and needs to be suppressed if a high gain amplifier at 1.3 μm. is required.

In fig.2 we show the evolution of the internal gain at 1.3 μm and the spectrum of this gain, compared with the fluorescent spectrum. We can see an irregular form in the gain curve which may be due to excited state absorption.

Figure 3 shows a result of our modelling with the evolution of the predicted gain at 1.3 μm with guide radius. The point marks our experimental result and one can see that with an increase in numerical aperture and a reduction in radius to about 2 μm. we may aspire to a gain of 8dB for a pump power of 35 mwatts.
At a pump power of 100 mw we predict a gain 20 dB but the ASE at 1.06 μm. will have to be suppressed. The curves shows an optimum guide radius, dependent upon numerical aperture, which corresponds to a radius . numerical aperture product of about 0.38 or a cut-off wavelength of 0.9 μm.

Our immediate aim is to produce an amplifier at 1.3 μm. with a four port output having zero insertion loss. A gain of 8 dB is required to compensate for the connection, background and splitter losses. The technology for suppressing the ASE (at 1.06 μm) , for reducing the guide cross-section, and pumping the smaller guide is well under way.

Conclusions.

We have demonstrated the feasibility of laser amplifiers at 1.3μm, operating in our graded index waveguide structures. Modelling of the amplifier has indicated the possibility of improving the opto-geometric properties and obtaining useful gains in the 1300nm band.

FIG. 1 AMPLIFIED SPONTANEOUS EMISSION AT 1.3 AND 1.05 μm.
FIG. 2  GAIN AT 1.3 MICRONS AS A FUNCTION OF PUMP POWER.

GAIN @ 1.3 microns.

GAIN AND FLUORESCENT SPECTRUM AT 1.3 MICRONS.

GAIN SPECTRUM @ 1.3 microns.

FIG. 3  PREDICTED GAIN AS A FUNCTION OF GUIDE RADIUS.

GAIN @ 1325 nm v. GUIDE RADIUS.

\( G (\text{dB}) \)  

Pump 100mw. NA = 0.25