SATURABLE ABSORBING QUANTUM WELLS AT 1.08 AND 1.55 MICRON WAVELENGTHS FOR MODE LOCKING OF SOLID STATE LASERS

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**Title and Subtitle**
SATURABLE ABSORBING QUANTUM WELLS AT 1.08 AND 1.55 MICRON WAVELENGTHS FOR MODE LOCKING OF SOLID STATE LASERS

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**Abstract**
Multiple quantum well designs were fabricated and tested at 1.55 microns. A series of 17 MBE fabrications were completed with deposits of various Al In As/Ga In As alloys deposited on Indium Phosphide substrates. The spectral absorbance band edge was characterized and data provided for each sample run. Several samples were specially reduced to minimal thickness and gold coated to minimize losses. The application tests for use as saturable absorber in erbium doped fiber laser systems were performed on selected samples by personnel at Rome Laboratory. Issues of consistent control and repeatability were also addressed.

**Subject Terms**
Multiple Quantum Well (MQW), Saturable Absorber, Modelocked Erbium Fiber Laser

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Introduction

Saturable absorbers constructed of semiconductor quantum wells have been successfully employed by others in mode locking Ti:sapphire lasers. In these applications, the saturable absorbing quantum well sample is positioned inside the laser cavity and passively, i.e. without electrical or optical control, causes the laser to mode lock. In a previous contract, we began developing quantum wells for mode locking Er$^{3+}$ fiber lasers in the $\lambda = 1.55 \, \mu\text{m}$ range. An additional interest is the development of quantum wells for short wavelengths for use with Nd:YAG lasers.

The present application requires saturable absorption near $\lambda \sim 1.55 \, \mu\text{m}$. A previous contract demonstrated the feasibility of constructing these saturable absorbing quantum wells in Al$_{0.48}$In$_{0.52}$As/Ga$_{0.47}$In$_{0.53}$As epitaxial layers grown on InP substrates. An aspect of the first contract that required attention is the non-reproducibility. One or two quantum well samples in that previous study functioned well in mode locking the Er$^{3+}$ fiber laser, many similarly prepared samples did not work as well.

This project is a continuation of the study, begun in the earlier contract, of the construction and evaluation of Al$_{0.48}$In$_{0.52}$As/Ga$_{0.47}$In$_{0.53}$As quantum well structures for mode locking of Er$^{3+}$ fiber lasers. The effects of MBE growth conditions and the post-growth fabrication on the performance of the mode locking ability of the samples was investigated. The low intensity absorption spectra of the samples were measured. After measurement of their cw, linear optical properties samples were delivered to K. Teegarden / R. Erdmann / M. Hayduk of Rome Labs for mode locking evaluation in an Er$^{3+}$ fiber laser.

Description of Samples

During the course of this project, a total of 17 molecular beam epitaxy (MBE) runs were made. The samples consisted of alternating Al$_{0.48}$In$_{0.52}$As and Ga$_{0.47}$In$_{0.53}$As layers on InP substrates; each layer was nominally 100 Å thick. In addition, 7 samples were thinned to less than 100 µm and gold coated (on the substrate side).

The samples are summarized in table 1.
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<th>FWHM pulse width (ps)</th>
<th>FWHM spectral width (nm)</th>
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</table>

Table 1. Summary of samples constructed for this project

Transmission spectra

The cw linear optical transmission spectrum of the 17 of the samples were measured with a commercial spectrophotometer. These 17 transmission spectra are shown in figures 1 - 17.
Discussion of data

This project concentrated on investigating which sample parameters have the dominant effects on the operation of the mode locking fiber lasers. The mode locking characteristics that were examined most thoroughly were the pulse widths and spectral widths (measured by Rome Labs personnel, M. Hayduk and W. Kaechele).

effect of growth temperature

Initially it was thought that the carrier lifetime in the semiconductor material is an important parameter. The lifetime is affected by the number of non-radiative recombination centers (defects) that are grown into the material. This defect concentration is a strong function of growth temperature — lower growth temperatures produces higher defect concentrations and, thus, shorter lifetimes. As can be seen in Table 1, the correlation between growth temperature and the mode locking characteristics (pulse width and spectral width) are very weak. The conclusion is that the earlier idea about the importance of carrier lifetime is not entirely correct. There may be some weak correlation between growth temperature and mode locking characteristics, but the growth temperature is not the dominant consideration.

effect of the number of quantum wells in the sample

A second sample parameter that was examined is the number of quantum wells in the sample, or the total thickness of the absorbing material. Samples 1945, 1947 and 1948 were constructed for this examination. A weak dependence of the mode locking characteristics on the number of quantum wells was found. Fewer wells produce shorter pulses.

effect of the thickness of the sample (after polishing)

Prior to the end of the present project, the sample that produced the shortest mode locked pulses was a sample from the previous project, #1305. Many tries to reproduce the results of this sample failed. Recently it was discovered that sample #1305 was polished to a thickness of only 200 µm, whereas most of the other samples had thicknesses in the 350 - 400 µm range. This is a matter that should be further investigated, however we feel that it is likely that the thickness of the samples is more important than previously realized.

effect of thinning and gold coating

Discussions between the consultant, G. W. Wicks, and Rome Labs scientist, M. Hayduk, led to the idea that extreme thinning of the substrates combined with a high reflector on the substrate side would improve the coupling of the light back into the fiber, and thereby improve the mode locking characteristics. Several samples were thinned to less than 50 µm and gold coated on the substrate side. These samples proved to be the best mode lockers by far. See for example, sample #1948. Prior to thinning to 50 µm and gold coating, the sample produced 23 ps pulse widths; after the thinning and gold coating, the sample produced 7 ps pulse widths. Clearly, thinning and gold coating are sample fabrication parameters that are the most important we have examined.
Conclusions

It has been demonstrated in this project that quantum well structures with saturable absorption near 1.55 \( \mu m \) can be very effective for mode locking \( \text{Er}^{3+} \) fiber lasers. The correlations between sample fabrication parameters and mode locking characteristics were examined. It was found that the fabrication parameters, which are most important in constructing samples for producing short pulse mode locking, are thinning to 50 \( \mu m \) or less and gold coating the substrate side.

A potentially useful direction for future research in this area is the construction of electrically controlled saturable absorbers for active, rather than passive, mode locking. Such structures might be useful to reduce jitter in mode locking repetition rates.
Sample 1630