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Design and Fabrication of a Mid Infra-Red Photonic Crystal Defect Laser in Indium Antimonide

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Abstract: This paper presents 2D FDTD modelling and prototype fabrication of a mid-infrared photonic crystal defect laser. The device is fabricated using a two stage Focused Ion Beam process which results in improved hole profiles.

OCIS codes: (140.0140) Lasers and laser optics; (140.3070) Infrared and far-infrared lasers; (140.4780) Optical Resonators

1. Introduction

There has been much interest in the design of photonic crystal (PhC) defect lasers in many different wavelength ranges and material systems [1,2] for applications such as single photon sources and sensing [3]. Very little work has been done in mid-infrared range from 3-4µm where a number of important sensing applications are found, and where, as yet, there are no practical room temperature semiconductor laser diodes [4]. PhC defect lasers enable the smallest possible lasing volume to be achieved and the very high Q factors obtainable will produce very low threshold devices which could improve their temperature performance. This paper presents the design and fabrication of a prototype device based on Focused Ion Beam (FIB) etching in the Aluminium-Gallium-Indium Antimonide system, which is a promising candidate for the realization of room temperature lasers emitting in the 3-4µm region. The prototypes are fabricated using conventional ridge laser devices which are post processed using FIB etching, enabling electrical injection to be achieved in the future. There are damage issues associated with FIB processing but annealing and careful choice of FIB etching procedure can minimize these [5,6,7].

2. Results

The 2D Finite Difference Time Domain (FDTD) method has been used to design the initial prototype along with an effective index model to describe the vertical layer structure. Figure 1 shows a top view of the structure which is an L1 cavity. The cavity is excited by a Gaussian modulated sinewave source from a small dipole placed at the centre of the cavity. The ring down is monitored in time and a FFT of this shows the resonant wavelength of the cavity. This is shown in figure 2 and the Q factor has been calculated to be 665.

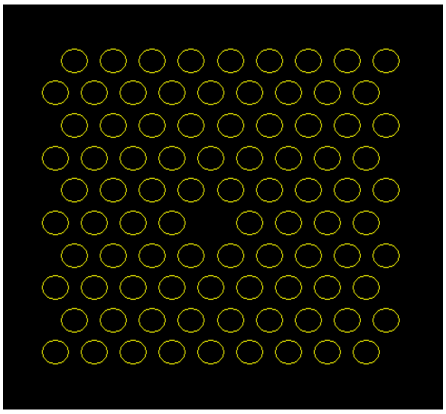

Fig 1: Top view of PhC defect laser structure in FDTD model

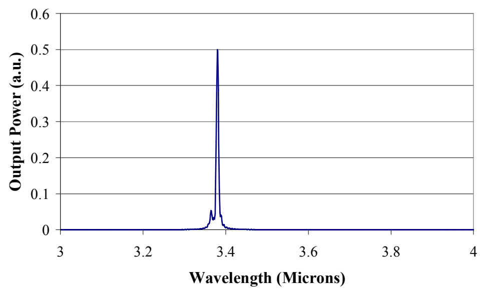

Fig 2: The resonant response as calculated by FDTD

In order to test a prototype device before E-beam lithography, Focused Ion Beam etching has been used [5,6,7]. This technique allows rapid post-processing of devices and techniques have been developed to overcome damage issues associated with the high energy beams. A two stage process has been developed where by an initial "end-on" etch removes material in the ridge to about 0.5µm above the quantum well layers and leaves a very flat surface for etching the PhC. The device is then rotated through 90 degrees and a vertical etch is used to

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create the PhC defect structure. This enables holes that have a good overlap with the optical mode to be achieved.

Fig 3: FIB image showing end-on etch through laser ridge and central PhC defect etch

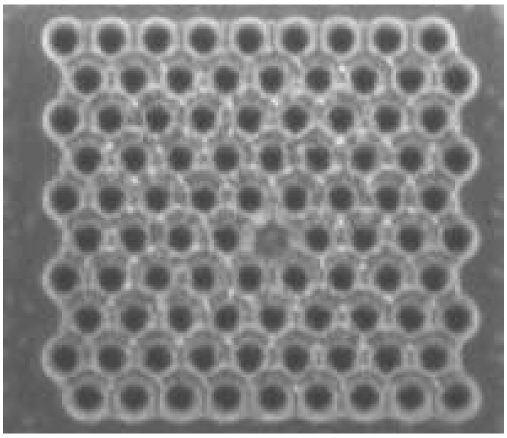

Fig 4: Zoom-in of PhC defect

Fig. 3 shows a FIB image near to the facet of a test laser, grown and fabricated at QinetiQ in Malvern [4]. Here around 4μm of ridge material has been removed with the end-on etch. This is then followed by the PhC defect etch which is shown in detail in figure 4. The excellent hole shape and periodicity can be seen here and it is believed that these holes are approximately 1.5μm deep. 3D modelling in other material systems suggests that this should be sufficient to maintain good Q factor and 3D modelling is now under way for this material system.

4. Conclusions

This paper has presented what is believed to be the first example of a PhC defect structure fabricated in the Aluminium-Gallium-Indium Antimonide system. It is hoped to perform both optical and electrical pumping on this structure to assess its performance as a laser. This will be followed by E-beam fabrication using QinetiQ's in-house facilities.

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