Photonic Crystal DFB laser array robust to optical feedback

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Abstract—**We demonstrate experimentally a new design for arrays of photonic crystal DFB lasers with precise wavelength spacing and high robustness to optical feedback.**

Distributed-feedback (DFB) lasers, optical feedback, photonic crystals (PhCs), semiconductor lasers

I. Introduction

Recently, it has been shown that photonic crystal defect waveguides can be used to fabricate second-order single-mode DFB lasers [1, 2]. Using affine deformation, these lasers can be arranged in array with a fine control over the frequency spacing between lasers [3]. The main limitation of this approach is optical feedback that introduces unpredictable frequency shifts and mode-hoping. Here, we present a novel approach dubbed “double deformation” that combines affine deformation of the photonic crystal and precise control of the width of the defect waveguide to achieve precise control of the laser frequency together with high robustness to optical feedback. The latter is obtained by a careful optimization of the Q factor of the cavity.

II. DFB Array using affine deformation

Here we consider lasers based on W3 ΓK defect waveguides (obtained by omitting 3 rows of holes along the ΓK direction in an hexagonal lattice, see figure 1. (b)). These lasers are fabricated on a InGaAs/GaAs membrane (of effective index 3.27 at 990 nm), using a lattice constant a=304nm and a filling factor of 25%, as described in [3]. We compare two different approaches to build an array of such lasers with a precise control of the emission frequency. In the first approach, each laser is deformed using affine deformation (see figure 1. (a)): the lattice period along a direction perpendicular to the waveguide is scaled: b’=αb together with the defect width w’=αw, where α is called the deformation. Using this approach, we designed arrays of fifteen 300µm-long lasers (see figure 2. (a)). A particular attention was devoted to cavity ends. First, the ends of the photonic crystal waveguide were slanted along the ΓM direction (see figure 2. (b) and (c)) in order to avoid optical feedback at that point. Second, two different types of output mirrors (corresponding to the end of the membrane itself) were designed: tilted ones (see figure 2. (b)) which provide the lowest possible level of feedback and normal ones (see figure 2. (c)) which introduce a moderate level of feedback. Across the array, deformation α increases from 0.86 to 1.00 (ie an increase of Δα=0.01 from one laser to the next). (This deformation range was chosen as is provided us with the best performances). To test the impact of optical feedback on laser performances, 4 arrays where fabricated: 2 with tilted output mirrors at both ends of the membrane, hereafter called “TT” geometry, and two with a tilted output mirror at one end and a normal output mirror at the other end, hereafter called “TN” geometry.

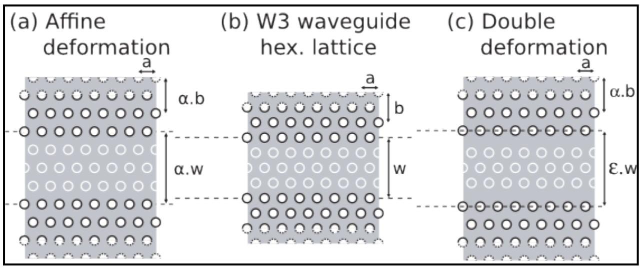

Figure 1. Geometry description: (b) undeformed W3 waveguide; (a) affine deformation; (c) double deformation

Lasers were tested under pulsed optical pumping (532nm – 10 ns – 1 KHz) and showed narrow DFB emission around 990 nm with an average pumping threshold around 500 µW.

On figure 3. , we report the difference of DFB emission wavelength between the center laser and each laser of the array as a function of the deformation used to design each laser. Arrays of the “TN” geometry (moderate feedback) are reported in (a) and arrays of the “TT” geometry (low feedback) in (b). In both (a) and (b), an overall increase of the emission wavelength across the array can be seen. However, with moderate level of optical feedback (a), several lasers are no longer single mode in particular in the range α=[0.93,0.97]. Moreover, unpredictable mode-hopping occurs and the two identical arrays TN1 and TN2 show different emission wavelengths for similar lasers. For low level of optical feedback (b), things get smoother: most the lasers remain single-mode and the wavelength dispersion around the overall trend is smaller. However, the two identical arrays still don’t exhibit the same emission frequency for each laser as some lasers seem to have hoped to a different mode. Even in this favorable condition of low feedback, the behavior of the array departs from what was expected (in particular all single-mode laser array with precisely tuned emission wavelength) and in an unpredictable manner that depends on minute changes of the feedback conditions at the laser output. Wavelength difference Δλ from two identical lasers in different arrays can be as high as 2 nm.

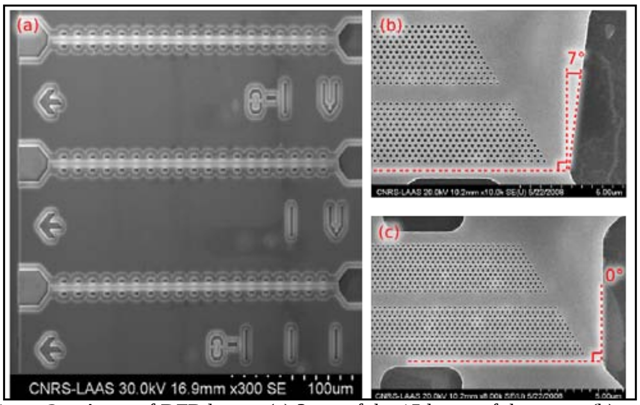

Figure 2. Array of DFB lasers: (a) 3 out of the 15 lasers of the array; (b) close-up on a tilted output mirror; (b) close-up on a normal output mirror.

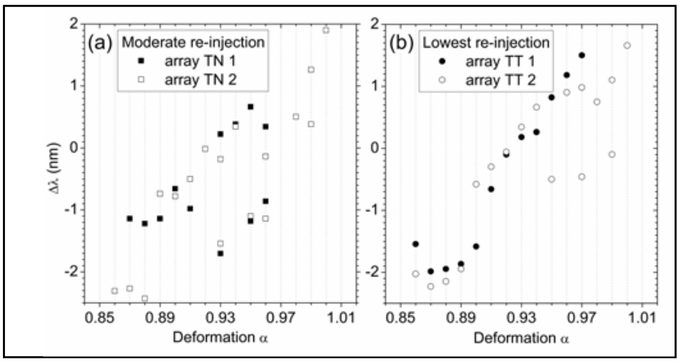

Figure 3. DFB laser arrays using affine deformation: evolution of the emission wavelength difference Δλ: (a) with one normal end introducing moderate level of feedback and (b) with two tilted ends ensuring lowest possible feedback.

III. DFB ARRAY USING DOUBLE DEFORMATION

In order to overcome the limitation of the affine deformation approach, we designed a novel approach that we called "double deformation". The main issue with affine deformation is that deformation α impacts on both the emission wavelength and the Q-factor of the waveguide. Indeed, using FDTD-3D simulations we have shown that Q goes down from 3.5×10^4 to 10^4 across the deformation range we used[4]. The other DFB degenerated mode experiences a Q factor that stays around 10^4. The problem is twofold: the Q factor is not high enough and the discrimination between the two degenerated modes gets too small for increasing deformations. Thus we need a way to optimize both the emission wavelength and the Q-factor discrimination, which requires at least two design parameters.

In double deformation approach (see figure 1. right), affine deformation is applied to the crystal: b'=αb, but for the defect width that is scaled independently w'=εw. We rely on closed-loop optimization: first α is used to aim at a target emission wavelength, then ε is used to optimize the Q factor of the most favorable mode and last we loop over until a stationary solution is achieved.

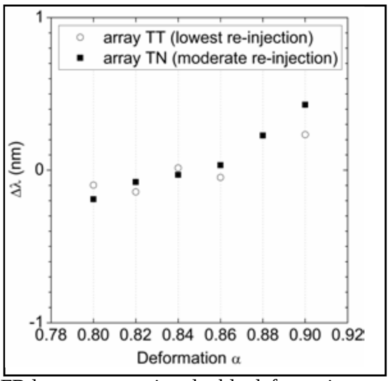

Figure 4. DFB laser arrays using double deformation: evolution of the relative emission wavelength with one normal end introducing moderate level of feedback (black squares) and with two tilted ends ensuring lowest possible feedback (white circles).

With this approach Q factors around 7×10^5 were achieved for the most favorable mode, while the other degenerated one exhibits Q factor of around 2×10^4. In fact, a broad optimum was found for ε=1.04 and α=0.7 to α=0.9. To demonstrate experimentally the benefits of this approach two arrays of 6 lasers each were designed and fabricated with a fixed ε=1.04 and α increasing from 0.8 to 0.9 across the array. One array uses the TN geometry for the output mirrors (moderate feedback) and one the TT geometry (low feedback). On figure 4. , we report the difference of DFB emission wavelength between the center laser and each laser of the array as a function of the deformation used to design each laser. For both geometries, ie for low feedback (white circles) and moderate feedback (black squares), the emission wavelength increases smoothly across the array. There are no major differences between the two (as opposed to affine deformation as can be seen comparing figure 3. (a) and (b)). Moreover, wavelength differences between two similar lasers stays below 0.2 nm, a tenfold improvement over affine deformation. Last, emission frequency evolution with deformation is 6 times slower than with affine deformation. This paves the way towards better frequency control and denser arrays.

IV. CONCLUSION

Here we have demonstrated that "double deformation" is an efficient way to fabricate arrays of single mode DFB photonic crystal lasers with a precise control of the emission frequency and a high robustness to optical feedback.

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