BPM Validation of the Modal Gain Measured with the Segmented Contact Method

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Abstract. *We determine, using a Beam Propagation Method technique, the accuracy of the well known method of evaluating the modal gain based on a ratio between the ASE powers obtained injecting current in one and two longitudinal sections of a device. We correlate the method accuracy with the sections length.*

Introduction

Segmented contact method has been widely used since its introduction to measure the gain [1] and loss [2] of active semiconductor materials analyzing the emitted amplified spontaneous emission (ASE) power.

The usual technique requires two equal-length electrodes on the semiconductor device under test [1]: first, amplified spontaneous emission (ASE) power $P(L)$ is measured injecting current only one section; then $P(2L)$ is measured injecting in both sections. In the laboratory set-up, output ASE power is then collected with an optical system to an OSA.

Net modal gain G is then estimated from the measures using the relation

$$G = \frac{1}{L} \log \frac{P(2L) - P(L)}{P(L)}. \qquad (1)$$

More complex solutions are also used, which require two electrodes with different lengths [2], or 3 or more electrodes, allowing estimating both the gain and the intrinsic material losses [3].

The aim of this work is to give a quantitative evaluation of the error affecting this measurement technique, and to determine the minimum device length required in order to obtain certain accuracy. We analyzed for simplicity the case of 1D layered structure, $n(y)$, using a two-dimensional BPM simulator. We calculated the ASE radiated power and its coupling with an optical system, and then we calculated the device gain. Results are shown for different modal gain values and different equivalent spot sizes of the collecting optical system.

Simulations procedure

Fig. 1 shows the layout of the device and the numerical discretization grid we used: y and z directions are discretized with step Δy and Δz respectively.

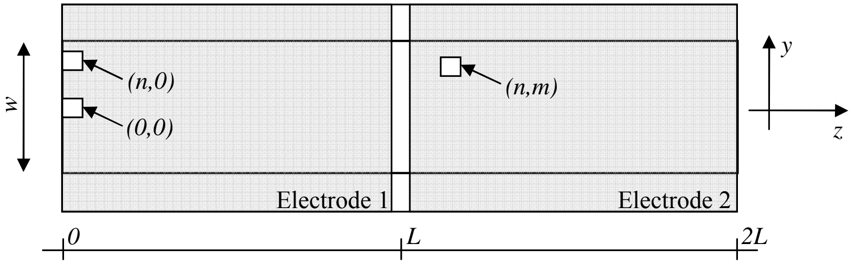

Fig.1 Layout of the device and 2D numerical discretization grid.

In the hypothesis of unsaturated regime of operation, the output ASE coupled to the output optical system can be computed using the following steps:

- We calculate first the field[1] $f(n,m;0)$ in all the structure generated by a point source in the middle of the active section ($y_s = 0$) of the waveguide in the plane $z = 0$ (see Fig. 2);

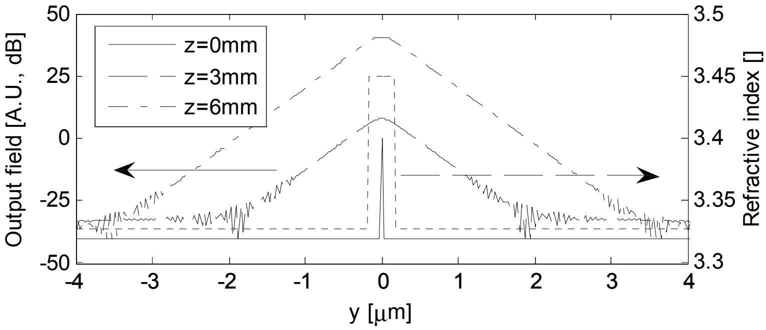

Fig.2 Calculated fields from a SE point source at various longitudinal sections and refractive index profile.

- We repeat this calculation for all the discretization points in the input section ($|y_s = s\Delta y| < w/2, z = 0$), obtaining the fields $f(n,m;s)$;
- From these results the ASE field contribution due to each SE source in the active region can be computed at the output section;
- The Fourier Transform of these fields can then be used to determine the transmitted fields at the output cleaved interface $F(k;m,s)$ from the spontaneous emission source at ($s\Delta y, m\Delta z$);

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[1] The first two indices indicate the position of the field sample at the coordinates ($n\Delta y, m\Delta z$), the third defines the position of the SE source which originates the field at ($s\Delta y, 0$).

- The projections of these fields on the Fourier Transform $F_f(k)$ of the equivalent spot size of the receiving optics allow to determine the contribution of each SE source $P(m,s)$; the total contribution from section $m\Delta z$ is therefore calculated as

$$P(m)=\sum_s \left[\left| \int F_f(k) F(k;m,s)\, dk \right|^2 \Big/ \int \left| F_f(k) \right|^2 dk \right].$$

- Finally, we obtain the gain for a cavity with length $2L = 2M\Delta z$ from Eq.1 as

$$G(2L)=\frac{1}{2L}\left[\log \sum_{m=M+1}^{2M} P(m) - \log \sum_{m=0}^{M} P(m)\right].$$

Results for modal gain and its relative error

In Figs. 3 and 4 we report the modal gain and relative errors obtained from the simulation of an InAs/GaAs QD active waveguide with $Al_{0.25}Ga_{0.75}As$ cladding having a spot size FWHM of 0.6μm.

In the case of Fig.3, we considered a 16cm^{-1} modal gain waveguide. The results dependence with the equivalent spot size of the receiver system clearly appears, and at least 750μm total device length is necessary to obtain a 10% relative error with a 1μm equivalent spot size. Wider spot sizes clearly require longer device in order to obtain the same error.

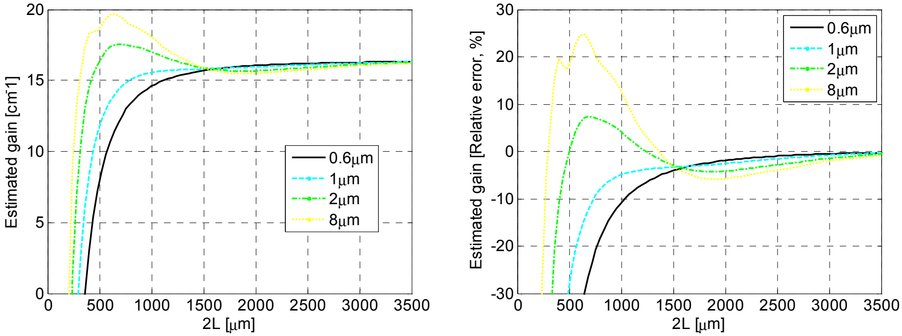

Fig.3 Estimated gain (left) and relative error (right) for a device with 16cm^{-1} net modal gain, for different equivalent spot sizes of the receiver system.

When working with lower gain values, a longer device is also required: for G=5cm^{-1}, at least 1.7mm are necessary to obtain a 10% relative error (Fig.4).

This behaviour clearly shows that segmented contact method gives correct results only when the ASE field coupled to the output optical system is sufficiently filtered from the unguided modal field components. Low modal gain operation and large spot size of the equivalent output optical system risk not guaranteeing a sufficient filtering effect respectively during the propagation in the waveguide or at the end coupling.

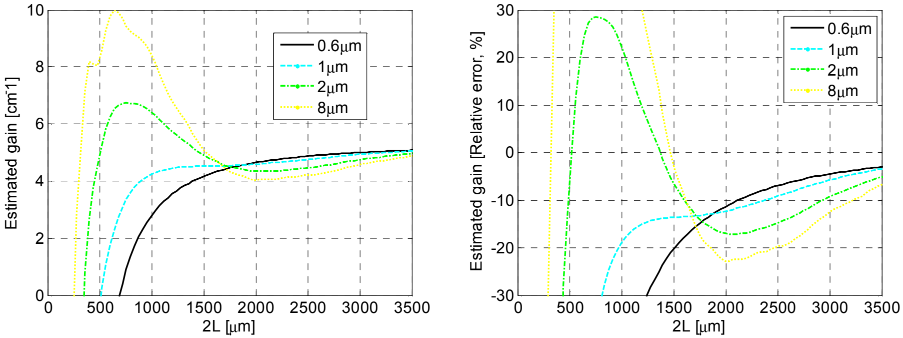

Fig.4 Estimated gain (left) and relative error (right) for a device with $5cm^{-1}$ net modal gain, for different equivalent spot sizes of the receiver system.

Conclusions

For the first time, to our knowledge, the multistrip modal gain measurement technique has been validated respect to its measurement error. Results from BPM simulation show that the error depends significantly on the ASE filtering capability of the receiving system and on the modal gain itself. Longer strips are necessary in order to measure low modal gain.

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References

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