

# Reflectance study of SiO<sub>2</sub>/Si<sub>3</sub>N<sub>4</sub> dielectric Bragg reflectors

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We present the results of reflectance investigations into SiO<sub>2</sub>/Si<sub>3</sub>N<sub>4</sub> dielectric distributed Bragg reflectors (DBR). The dielectric multilayers forming reflectors have been deposited by plasma enhanced chemical vapour deposition (PECVD) on silicon substrates. Such structures can be utilised in vertical cavity surface emitting lasers (VCSELs) and resonant cavity light emitting diodes (RC LEDs).

## 1. Introduction

The laser cavity of VCSEL is usually constructed normal to the substrate plane by stacking multilayer films including an active region, spacer and two mirrors. Such a structure forms a one-dimensional Fabry–Perot resonator. The mirrors can be formed with a periodic stack of quarter wavelength thick layers of high and low refractive index material. The layers can be deposited via molecular beam epitaxy (MBE). The reflectivity of Bragg reflectors depends on the thickness of individual layers in the mirrors, therefore the growth rate of these layers has to be controlled with an accuracy better than 2%. To achieve this level of process control, a real time monitoring of the growth is required.

In the typical VCSEL structure the pumping current flows through the reflectors. When the changes in the refractive index at the interfaces between different layers composing a Bragg reflector are abrupt, the electrostatic potential is discontinuous and the potential barriers at the layer interfaces are formed [1]. Such effect results in an extra series resistance of the structure and causes increase in the device temperature, which results in the decrease in the laser efficiency. It is an undesirable effect and in some cases may lead to the degradation of the laser [2]. The above effect is particularly strong for p-type reflectors for which band bending at the potential discontinuities is more pronounced.

## 2. Structure details and experiment

A new construction of VCSEL has been developed. The upper, normally p-type DBR, responsible for the high series resistance of the laser, has been replaced with a dielectric

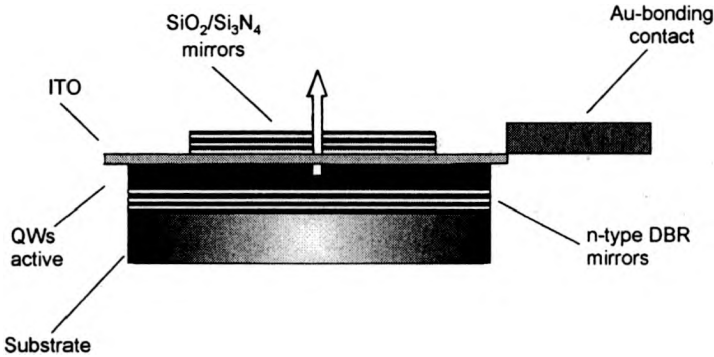


Fig. 1. Scheme of laser structure with  $\text{SiO}_2/\text{Si}_3\text{N}_4$  dielectric Bragg reflectors.

Bragg reflector, deposited on the transparent and conducting ITO (indium tin oxide) layer (Fig. 1).

Numerical methods (based on the transmission matrix method) or analytical methods (using the coupled modes method) are used for making a project of Bragg reflectors with known reflection coefficients in particular range of wavelength [3]. The operation of VCSEL requires the reflection coefficient of the dielectric DBR equal to at least 99,9%, similarly as it is for the semiconductor type DBR. To be useful for the device purposes, the ITO layer should exhibit the optical transmission higher than 80%, having simultaneously the electrical resistance  $r < 10^{-4} \Omega\text{cm}$ . The dielectric multilayers, which form the reflectors, have been developed using the PECVD method in the Plasmalab System 100 reactor. It is a diode reactor with parallel electrodes.

This method enables the deposition of dielectric layers on the Si,  $\text{SiO}_2$  and GaAs substrates. The measurements reported in this paper have been performed at the structures deposited on the Si substrates.  $\text{SiO}_2$  is a material with the relatively low refractive index equal to 1.4981 for  $1 \mu\text{m}$ , whereas the refractive index of  $\text{Si}_3\text{N}_4$  equals 1.8944 for  $1 \mu\text{m}$ . The PECVD deposition process gives a good layer thickness uniformity (thickness variations are less than 1%). Layers forming DBR mirrors were deposited at following process conditions:

i)  $\text{SiO}_2$  – temperature  $300^\circ\text{C}$ , pressure 1 Tr, generator frequency 13.56 MHz, generator power 15 W, the flow of  $\text{SiH}_4^{2\%}/\text{N}_2^{98\%}$  –  $1000 \text{ cm}^3/\text{min}$ , the flow of  $\text{NH}_3$  –  $20 \text{ cm}^3/\text{min}$ ;

ii)  $\text{Si}_3\text{N}_4$  – temperature  $300^\circ\text{C}$ , pressure 1 Tr, generator frequency 13.56 MHz, generator power 20 W (100 kHz) and 15 W (13.56 MHz), the flow of  $\text{SiH}_4^{2\%}/\text{N}_2^{98\%}$  –  $1000 \text{ cm}^3/\text{min}$ , the flow of  $\text{NH}_3$  –  $20 \text{ cm}^3/\text{min}$ , ratio between the impulse time of generator “13.56 MHz” to impulse time of generator “100 kHz” equals 4.

The reflectance measurements were performed using a two-beam absorption spectrophotometer (LAMBDA type), in the large spectral range: from 400 nm to 1400 nm. The optical set-up of this spectrometer, equipped with reflectance option, is similar to the standard set-up used for the reflectance measurement [4]. At the first stage the structures composed of 5 pairs of  $\text{SiO}_2/\text{Si}_3\text{N}_4$  were deposited but the value

of the reflection coefficient for such structures was too low for practical application of these structures in the construction of VCSELs. This necessitated further works on the deposition of more pairs of  $\text{SiO}_2/\text{Si}_3\text{N}_4$  layers.

### 3. Results and discussion

Two samples have been investigated using the reflectance technique. First of them includes DBR composed of 5 pairs of  $\text{SiO}_2/\text{Si}_3\text{N}_4$  layers, the second one is composed of 10 pairs of the layers. The results of the measurements are shown in Figs. 2 and 3, respectively. The spectra of reflectance exhibit plateau for desired spectral range 900–1100 nm. Beyond this range we can observe characteristic minima and maxima

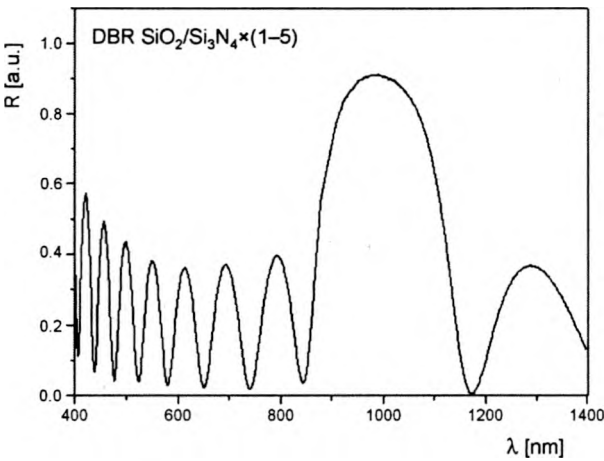


Fig. 2. Reflectance of spectra for 5 pairs  $\text{SiO}_2/\text{Si}_3\text{N}_4$  dielectric Bragg reflectors.

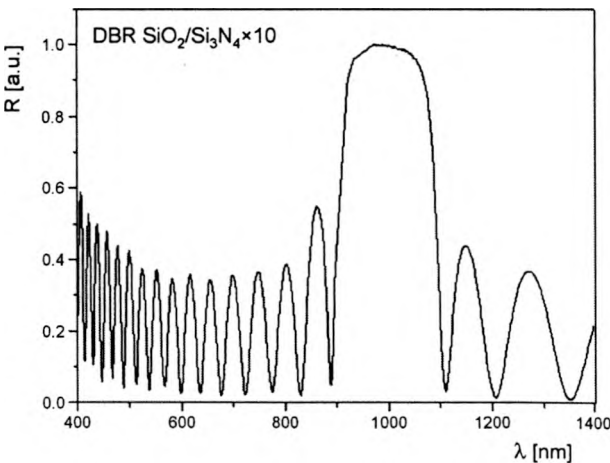


Fig. 3. Reflectance of spectra for 10 pairs  $\text{SiO}_2/\text{Si}_3\text{N}_4$  dielectric Bragg reflectors.

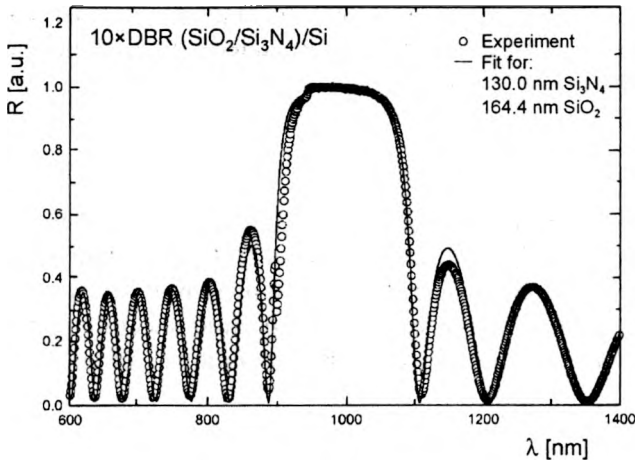


Fig. 4. Numerically calculated and experimental spectra of the reflectance for 10 pairs  $\text{SiO}_2/\text{Si}_3\text{N}_4$  dielectric Bragg reflectors.

of reflectance, which follow from the interference of waves propagated through the structure.

The numerical simulation has been made with the use of transfer matrix approximation for a sample with  $\text{SiO}_2/\text{Si}_3\text{N}_4$  DBRs. Figure 4 shows the comparison of experimental and calculated reflectance spectra for 10 pairs  $\text{SiO}_2/\text{Si}_3\text{N}_4$  DBRs [5].

The value of the reflectance at the maximum equals 90% and 99.9% for DBRs composed of 5 and 10 pairs of  $\text{SiO}_2/\text{Si}_3\text{N}_4$  layers, respectively. Thus, the structure composed of 10 pairs of  $\text{SiO}_2/\text{Si}_3\text{N}_4$  layers meets design requirements for VCSELs and can be used as a reflector in practical devices.

#### 4. Summary

We have demonstrated that  $\text{SiO}_2/\text{Si}_3\text{N}_4$  dielectric Bragg mirrors provide high reflectance even for the relatively low number of pairs of the layers. The studied sample with 10 pairs of the layers exhibits reflectance of about 99.9%. For comparison, to reach that value of reflectance with a standard GaAs/AlAs reflector at least 20 pairs of the layers are required. At the same time, dielectric DBRs allow to avoid the problems connected with the high resistance characteristic of semiconductor reflectors. The results demonstrate usefulness of such structures in modern optoelectronic devices, like VCSELs and RC LEDs.

#### References

- [1] BUGAJSKI M., MUSZALSKI J., OCHALSKI T.J., KAÇKI J., MROZIEWICZ B., *Acta Phys. Pol. A* **101** (2002), 105.
- [2] SALE T.E., *Vertical Cavity Surface Emitting Laser*, Research Studies Press LTD., Taunton, Somerset, England 1995.

- [3] CHILWELL J., HODGKINSON I., *J. Opt. Soc. Am. A* **1** (1984), 742.
- [4] BACHER K., PEZESKI B., LORD S.M., HARRIS J.S., *Appl. Phys. Lett.* **61** (1992), 1387.
- [5] MUSZALSKI J., private communication.

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