Modeling Component-based Bragg gratings Application: tunable lasers

Rachida HEDARA, Mohammed .CHIKH-BLED
Telecommunication Laboratory, Department of Telecommunications
Technology Faculty, B.P.119 University Aboubekr Belkaïd
Tlemcen, 13000 Algérie

Abstract
The principal function of a grating Bragg is filtering, which can be used in optical fibers based component and active or passive semi conductors based component, as well as telecommunication systems. Their ideal use is with lasers with fiber, amplifiers with fiber or Laser diodes. In this work, we are going to show the principal results obtained during the analysis of various types of grating Bragg by the method of the coupled modes. We then present the operation of DBR are tunable. The use of Bragg gratings in a laser provides single-mode sources, agile wavelength. The use of sampled grating increases the tuning range.

Keywords: *Integrated optics, WDM, Guide of wave, Bragg grating , Telecommunications optical.*

1. Introduction

Optoelectronic components appear as key players in telecommunication architecture systems based on optical fiber, as they are present at all levels of information transmission, in order to transmit an information from a point to an other it is necessary to use a laser source for generating signals in form of a coherent optical wave. Then we must use an optical modulator that encodes the information in two levels ("0 " and "1 " optics). Afterward the optical fiber is used as an underlying support of transmission.
Regardless the significant progress made for reducing propagation losses in optical fibers. It is necessary to amplify the signal during its propagation, in order to avoid losses induced by the fiber [1].

The decreasing in spectral congestion has allowed evaluating the transmission mode giving the possibility to use multiple wavelengths in the same optical fiber. This is called wavelength multiplexing, which forms several independent transmission channels: each channel corresponds to a wavelength that is sent into the fiber. The demultiplexing is the inverse operation that performs the separation and the collection of signals coming from different channels.
The wavelength of these channels is located around 1.55µm which is the band of low attenuation in optical fibers.
In optical grating currently installed, DBR lasers play perfectly the role of a transmitter. Nevertheless, the constraints imposed on telecommunications and the emergence of new applications will promote the implementation of new laser generation sources.

2. Generality of the Bragg grating

Interests in the study of periodic structures, as well as of wave propagation in periodic medium are a phenomenon well known in solid physics.
The propagation of electromagnetic waves like light in a waveguide with a periodicity is a phenomenon quite similar, except that this wave is so confined, and the interactions do not appear in the direction of propagation. The introduction of such periodic modulation in waveguide structures has given rise to many devices such as optical filters.

A Bragg grating in an optical fiber is a periodic variation of refractive index in the core which is medium of optical signal propagation [2].
The periodic modulation introduced into a passive waveguide is the index of refraction of one or more of its constituent materials. This is called grating case volume figure Fig.1. (b).

A technique applicable to semi-conductors, for which the effects presented earlier are not sufficient, this technique introduce a periodic modulation through a physical corrugation in a waveguide structure of the by an engraving techniques.

This is called surface grating, figure Fig. 1. (a).

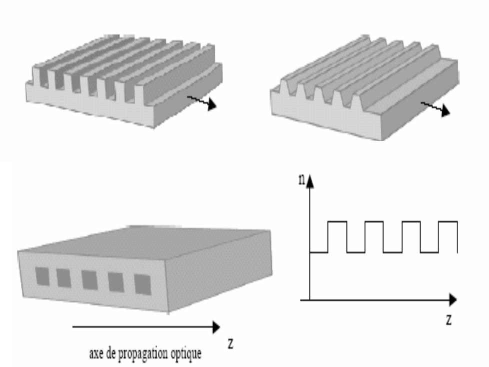


Fig. 1 (a) Surface grating, (b) Density grating

The Bragg grating can also be shorter in order to be easily integrated compared to fiber-based components in photonic circuits.

The physical phenomenon involved in a Bragg grating and their theoretical analysis, are similar for all profiles.

A fine periodic corrugation engraved on the surface of a waveguide creates a uniform coupling between light propagating in the forward direction and the one propagating in the backward direction. The grating is then analogous to a mirror formed by stacking periodic dielectric layers having different refractive indices.

3. Reflection coefficient of a Bragg grating

The Bragg grating presented a maximum reflectivity for the wavelength satisfying the Bragg condition [4].

$$\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

λ_B : Bragg wavelength

n_{eff} : the effective index of optical mode

Λ : Bragg period

We then obtain the expression of the maximum reflectivity of a uniform Bragg grating.

$$R_{MAX} = R(\lambda_B) = \tanh^2(kL) \qquad (2)$$

The maximum reflectivity directly depends on the product's value kL, therefore we can define two types of grating: high and low-coupled grating.

3.1 Case of low coupling

When the multiplication kL is smaller than 1, the spectral response in reflection of the Bragg grating has a profile similar to the square of the sinc function centered on the Bragg frequency.

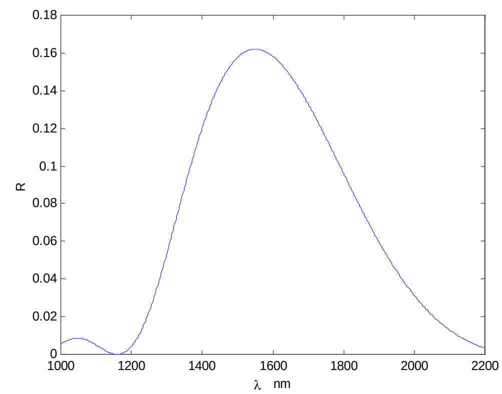


Fig. 2 Responses spectral reflection. Case of low coupling ($kL \leq 1$)

3.2. Case of strong coupling

When the multiplication kL is widely above 1, the profile of the reflection spectrum has a plate at R = 1 becoming more pronounced when kL increases.

In this case, the network has very high reflectivity. Also we can observe band of wavelengths, called stopband, where the light is considered totally reflected. It is centered on the Bragg wavelength (λ_B =1550).

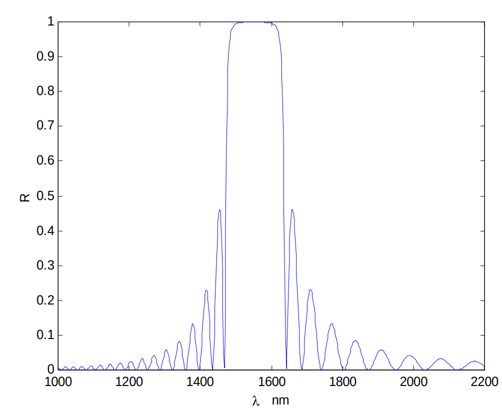


Fig. 3 spectral response in reflection. Case of strong coupling (kL >1).

4. Analytical formulation of power reflector [3]

If most indices are purely real and we consider the stacking to its wavelength design for which the layers are exactly quarter of the wave, then completely analytical formulations of the reflectance. Taking the conventions of mirrors we obtain:

$$R_{2N} = \left[\frac{1 - \frac{n_S}{n_0}\left(\frac{n_L}{n_H}\right)^{2N}}{1 + \frac{n_S}{n_0}\left(\frac{n_L}{n_H}\right)^{2N}} \right]^2 \qquad (3)$$

n_S :the index of the substrate, n_0 index of incident medium,
n_H :the index of the material with high index
n_L: the index of the material with low index.

The use of this simplified formula shows that it is advantageous to have a contrast between the indices *nL* and *nH* is very important in the mirror to minimize the ratio *nL/nH*.

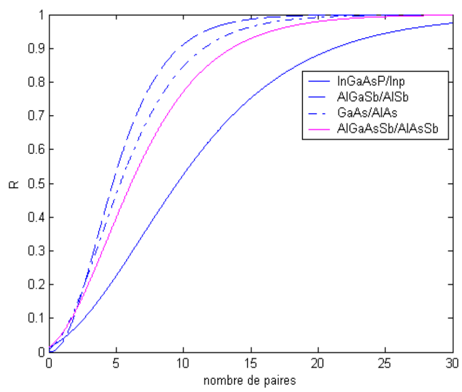


Fig. 4 Reflectivity as a function of the maximum number of pairs of layers

The advantage provided by materials with high index ratio *nL/nH* is evident on this graph. Although it seems impossible to obtain a reflectance higher then 99.9% with the system InGaAsP/InP on InP, while this is quickly achieved with systems AlGaSb/AlSb on GaSb and GaAs/AlAs on GaAs and lesser with the system AlGaAsSb/AlAsSb on InP.

5. Bragg grating individuals

Until now we have assumed that gratings are perfectly periodic along structure with starting point and end well defined. Often, either by design or because of used manufacturing techniques, the Bragg grating deviates slightly from the perfect structure.

The use of Bragg gratings in various optical components, in its simplest form, called the uniform grating is widespread. Nevertheless, the emergence of new functions of passive and active components needs more efficient grating. This is why this gratings are more particular than the sampled grating and vertical grating become necessary.

6. Sampled Bragg grating

A sampled grating consists of a right grating at a wavelength probably defined, multiplied by a sampling function. It is possible to model the reflectivity complex of sampled grating using the theory of coupled mode and the theory of transfer matrices, but it must first define the key parameters which modify its properties in phase and amplitude.

A sampled grating is a conventional grating from which we remove portions periodically. In other words, there is an alternation between sections with gratin and sections without a grating as described in Fig.

A Bragg grating wavelength λ_{B} ((defined by the step Λ and the effective index n_{eff}) and located on a distance Z_1 with a coupling coefficient the grating is then repeated m times (number of sampling periods) with a period Z_0. The total length of sampled grating is $L_{Tot}= mZ_0$. The spectral response of this grating is the Fourier transform of the profile index. The result is a comb Bragg reflectors, regularly spaced with the sampling frequency ISL_{SBG} most often expressed in GHz.

$$ISL_{SBG} = \frac{c}{2n_{eff}Z_0} \qquad (5)$$

6.1 Model Description

The multiplication of a Bragg grating with a sampling function provides a sampled grating. The Fourier components of the sampled grating can be obtained by the convolution of the Fourier component of a Bragg grating by a comb of Fourier components of a sampling function.

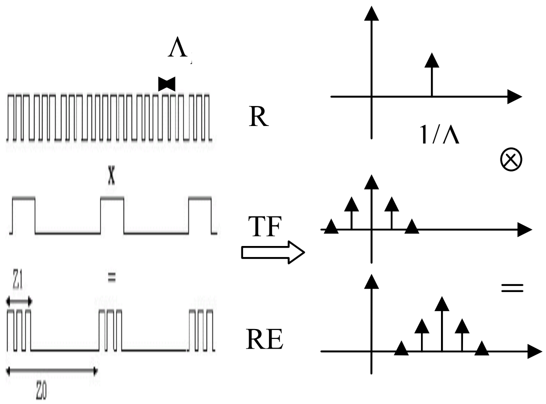


Fig. 5 grating sample space to real space Fourier

The reflectivity of this structure can be obtained from the coupled mode theory, which predicts that each component of the spatial Fourier series decomposition of the permittivity create a peak in the overall spectrum of reflections.

The q th component Δ ε (q) on the sampled grating is connected to the single Fourier component Δ 0 0 ε of an unsampled grating by the relation [5]:

$$\Delta\varepsilon(q) = \Delta\varepsilon_0 \frac{Z_1}{Z_0} \frac{\sin \pi \; qZ_1 / Z_0}{\pi \; qZ_1 / Z_0} \exp[-j\pi q Z_1 / Z_0] \quad (6)$$

If the coefficient of coupling portions of the grating is k_0 then the coupling coefficient of the qth Fourier component of the total sampled grating is:

$$k(q) = k_0 \frac{Z_1}{Z_0} \frac{\sin \pi \; qZ_1 / Z_0}{\pi \; qZ_1 / Z_0} \exp[-j\pi q Z_1 / Z_0] \quad (7)$$

It is possible to know the reflection coefficient of the field in a Bragg grating,by introducing the coupling coefficient of the sampled grating, it is then possible to determine the reflectivity of complex grating sampled.

$$r(\lambda) = \sum_{-q}^{q} \frac{jk^*(q) \;\; \sin(Q(q))L_{Tot}}{Q(q)\cos(\theta(q)L_{Tot}) - j\Delta\beta(q)\sin(Q(q)L_{Tot})} \quad (8)$$

Or

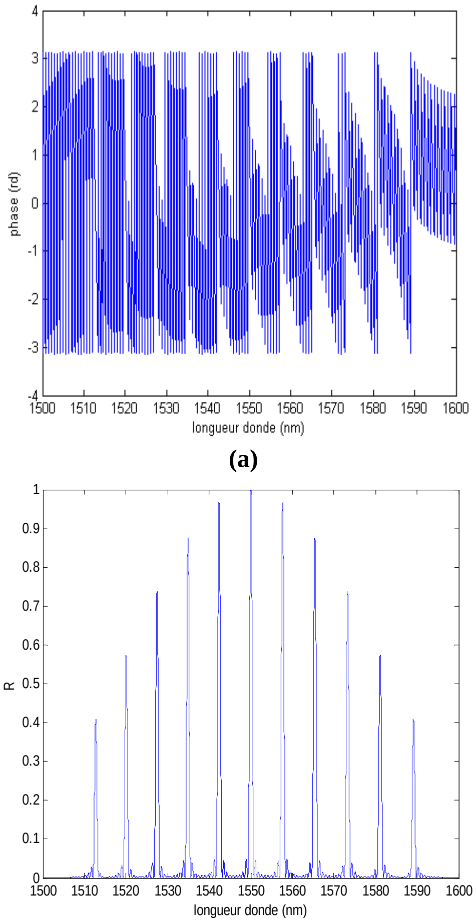
$$\Delta\beta(q) = \frac{2\pi n_{eff}}{\lambda} - \frac{\pi}{\Lambda} - \frac{\pi q}{Z_0} \quad ; \quad (Q(q))^2 = (\Delta\beta(q))^2 - |k(q)|^2$$

The evolution of the field in a periodic structure is described by its complex reflectivity. The parameters for modifying the spectral properties are the total length of L_{SBG}, the coupling coefficient of the grating $k(q)$, the sampling period Z_0 and the opening ratio h. The influence of these parameters can be modeled in a sampled grating but also in the particular cases of a non-sampled Bragg grating with opening ratio unit (Z0 = Z1). We can also define the bandwidth of the peak q between two zeros by:

$$\Delta\lambda_{bw}(q) = \frac{\lambda^2}{\pi \; n_g} \sqrt{|k(q)|^2 + \frac{\pi^2}{L_{Tot}{}^2}} \quad (9)$$

6.2 Simulation of a Sampled Bragg grating

Two additional parameters define the sampling function (opening ratio h sampling period Z0). Modeling allows the calculation of the complex reflectivity of a sampled grating phase φ[λ] = Arg[r[λ]] and amplitude.
The models below are the typical characteristics of sampled grating, engraved in InP [6] [7]. These dimensions widely studied and optimized are: Z_0= 450µm, k_0 =150cm^{-1} et h=10%.



(a)

(b)

Fig. 6 (a) Phase (rad) in a sampled grating
(b) Reflectivity (amplitude) in a sampled grating

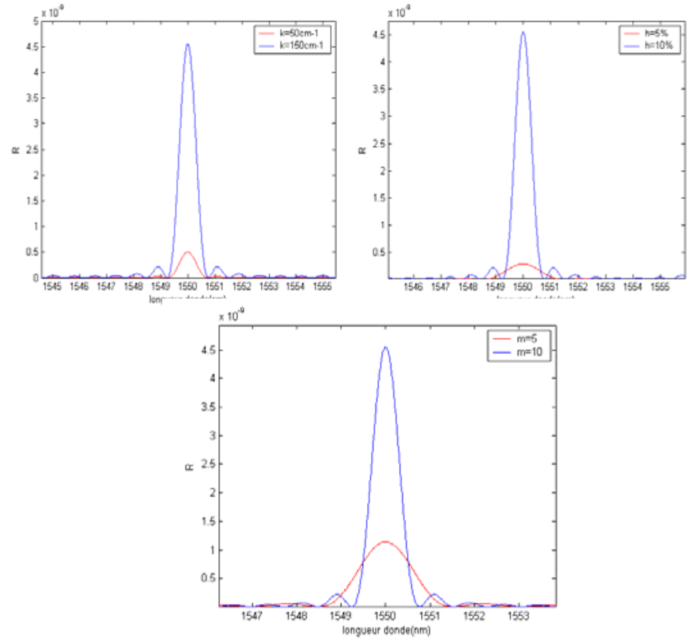


Fig. 7 Influence of (, m, h) on the maximum reflectivity and bandwidth

The modification of one parameter changes the overall properties of the sampled grating

The variation of coupling coefficient can increase the reflectivity of the grating and the bandwidth of the peaks.

In addition, the modified opening ratio changes the Envelope of The Sampled grating (number of peaks in the envelope) but also changes the reflectivity.
The number of periods and consequently the length of the sampled grating reflectivity will increase grating and reduces the bandwidth of the peaks.
The value of a grating is sampled to obtain a structure which has a low coefficient of effective coupling. From a technological point of view, it is difficult to reach values of coupling coefficients low.

The bandwidth of the reflection peak depends directly on the value of the effective coupling coefficient of the structure. So if you have a very small value of coupling coefficient, while retaining a correct length of the structure we obtain a peak very close and very selective what is interesting in multiplexing systems in dense wavelength (DWDM).

We saw here the main advantages offered by the individual networks that are the networks sampled. However we have also seen that their use requires compromises that can sometimes be difficult.

7. DBR tunable lasers

7.1 Principle of Operation

The passive DBR of a length of 1 mm is located in the RW section near the back face of the laser. while the Bragg grating and RW were defined by a lithography projection using a wafer stepper I-line and transferred to the surface of the semiconductor by dry etching process [9].
An effective reflectivity of the DBR around 60% was obtained by well designed length of the no engraved region within the grating [9].

The spectrally selective element is a policy grating, forcing the laser emission at the Bragg wavelength, while the output power and beam properties are imposed by the conical structure amplifier. Indeed, Bragg gratings have become essential optical components in recent years, with high spectral selectivity, low loss, limited drift wavelength (~ 0.01 nm / K) and the reflectivity of some 0.1% at 100 % [10].
Once the laser is manufactured, the spectrum of the gain condition is likely to continue since it is intimately linked to the material and structure. That leaves two possibilities:

A. **Changing the Status Phase**

The phase condition is related to the geometry of the cavity. In reality, the distances seen by the optical wave are n × L. We can not of course change the physical length of a laser made from a solid material.
However, it is possible to modify slightly the index of the material that composing it by several techniques.

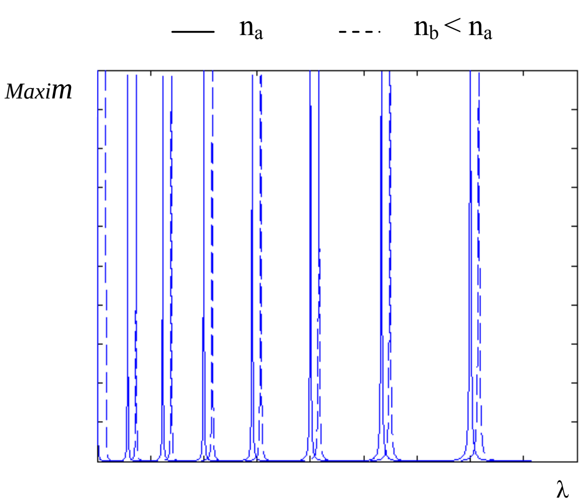


Fig. 8 Changing the phase condition

By changing the index of the optical wave guide, we change the distribution of the maxima in the core-Perot (Fig. 8), since it creates an additional phase shift.
We can also note that the evolution of the wavelength depending on the index is linear. Thus, the evolution of the wavelength depending on the phase parameter is done continually.

B. Changing the filtering Bragg Area

The filter response is also dependent Bragg indices of the materials considered

"The change in each of these two parameters causes significant changes in the spectrum emitted by the laser".

We assume here that the changes made to the index of the material are relatively low, and quantitatively the same for each of the two indices considered. We will see later that this corresponds to the behavior of compounds III-V.

$$n_1 \rightarrow n_1 + \Delta n$$
$$n_2 \rightarrow n_2 + \Delta n$$

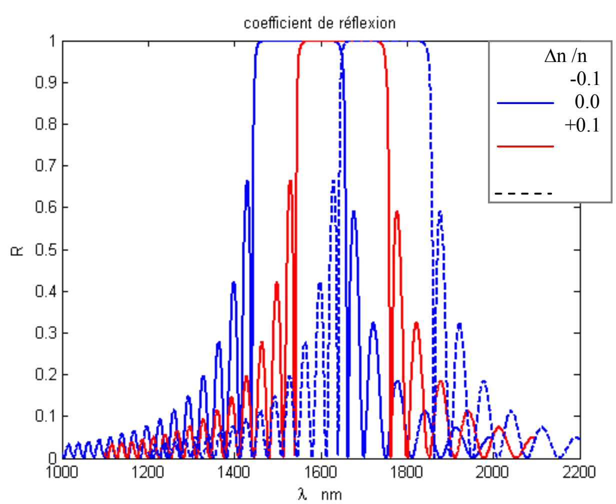


Fig. 9 Evolution of the Bragg filter according to the indices of materials

By injecting this variation in the numerical model, we obtain the results shown in Figure 9.

Thus we observe an effect of translation of the spectral bandwidth available, with a negligible effect on the bandwidth.

We simulated the evolution of the central wavelength of the Bragg mirror based on the relative variation of the index layers.

We obtain an almost linear deviation of the center wavelength depending on the index variation.

Thus, the filter Bragg will be able to move to spectrally to select a mode of Fabry-Perot and change the condition of laser oscillation.

7.2 Accordabilité of a Laser

We have identified two ways to tune a laser DBR:

A. Continuous tunability: the phase condition of the Fabry-Perot
B. Discontinuous tuning: by translation of the Bragg filter.

The tunability with the phase condition is often insufficient: the range of wavelengths obtained is too small.
However, the tunability of the Bragg filter allows a good tuning range, but achieves certain wavelengths, those defined by the Fabry-Perot.

The tunability of the phase region allows for continuous excursions of about 100 GHz, that allowed by the Bragg zone corresponds to excursions of 2 THz. This limitation is due to the low index variation depending on the injection current, and not to the spectral spread of the condition of material gain. The dependence of output power, the quality and optical spectrum of the input currents will be shown.

Various measures used to improve the modulation efficiency of a diode laser DBR similar to those presented in [11] and [12], emitting at 1060 nm.

8. Conclusion

The realized work in this paper concerns the theoretical depth of the Bragg gratings and sees their applications in optical telecommunications. The objective of this work is to study types of integrated structures periodic Bragg gratings or sampled.

Bragg gratings are components in telecommunications systems they are ideal when used in combination with fiber lasers, fiber amplifiers or laser diodes. In addition to their flexibility and their design makes them very attractive for applications to the user's needs [8].

The use of Bragg gratings in a laser provides single-mode sources, agile wavelength. The Bragg grating acts as a mirror that is reflecting only one wavelength, thereby effectively select a single mode source.

References

[1] Brackett, C.A; « Dense Wavelength Division Multiplexing networks: principles and applications», IEEE Journal of selected areas in communications, 1990, Vol 8, N°8, p.948-964.

[2] S.Garidel ; « Fabrication des réseaux de Bragg particuliers par lithographie électronique : application à la réalisation de dispositifs photoniques et optoélectroniques sur matériaux de la filière InP »,Thèse de doctorat, Lille, 2004.

[3] T. Zeno.; «Optoelectronique-composants photonique et fibres optiques», Ellipses-2001.

[4] M. Born , E .Wolf; «Principles of Optics», Pergamon Press, New York, 1970.

[5] A .Yariv; « Coupled-mode theory for guided-wave optiucs», IEEE journal of Quant um electronics Volume: 9 Issue: 9, septembre 1973, page: 199-933.

[6] G .Bjork, O .Nilsson; «Anew exact and coefficient numerical matrix theory of complicated laser structures: proprieties of asymmetric phase-shifted DFB lasers», journal of light wave technology, volume: 5 Issue: 1, Jan 1987, page: 140-164.

[7] B .Mason, J .Barton, G.A .Fish, L.A .Coldren, S.P .Denbaars; «Design of sampled grating DBR lasers with integrated semiconductor optical amplifier», IEEE photonics Technology letters, Volume: 12 Issue: 7, July 2000, page: 762-764.

[8] Pierre Aschieri; «Introduction aux télécommunications optiques», note cours optique université Nice version 12, 2004.

[9] K-H. Hasler, B .Sumpf, P .Adamiec, J .Fricke, H .Wenzel, G .Erbert, G .Tränkle; «Improving the modulation efficiency of high-power distributed Bragg reflector tapered diode lasers» Applied Physics B lasers and optics Springer- Verlag 2010.

[10]g.lucas-leclin1,d.paboeuf1, p .georges1, holm2 p, j. andersen2 ,b .sumpf3, g .erbert; «Wavelength abilization of extended-cavity tapered lasers with volume Bragg gratings» Applied Physics B Lasers and Optics ringer- Verlag 2008.

[11] B.Sumpf, K.H.Hasler, P. Adamiec, F. Bugge., J .Fricke, Ressel. P, H .Wenzel, G .Erbert, G .Tränkle, Proc. SPIE 7230, 72301E (2009)

[12] B.Sumpf, K. H .Hasler, P .Adamiec, F .Bugge, F .Dittmar, J .Fricke, H .Wenzel, M .Zorn, Erbert , G .Tränkle, IEEE J. Sel.Top. Quantum Electron. 15, 1009 ,2009.