Optical Gratings for Electronic Controllable Wavelengthsensitive Switches on Si/SiGe Heterostructures

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Abstract

Characteristics of optical gratings on Si/SiGe heterostructures for optical band-pass filters will be discussed. The bandwidth can be down to 0.1 nm. By reducing the refractive index of the SiGe layer due to injected free carriers it is possible to move the transmission band to lower wavelengths. In DWDM systems (dense wavelength division multiplexing) transmission channels can be selected separately. Furthermore the structure can be used as an electronic adjustable switch.

1 Description of structure

The structure consists of two parallel optical waveguides, coupled by two gratings. The gratings are realized by etching periodical lines into the SiGe layer. In transversal direction light guiding is ensured by a higher refractive index of the SiGe layer compared to the surrounding layers and in lateral direction by an etched ridge in the n-Si layer (Fig.1). The lines of the gratings have an angle of 45° to the direction of propagation of light. The width of the grating is equal to the width of the ridge.

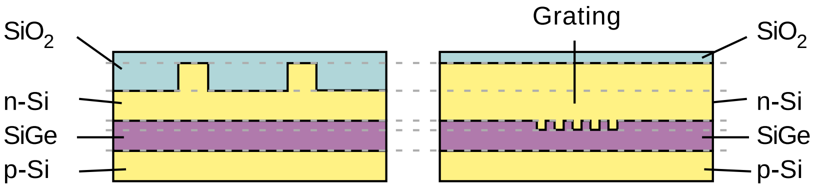

Figure 1: Front and side view of the structure

Because of the 45° angle both gratings are coupled. Furthermore the lines of both gratings are oriented at a right-angle to each other. Therefore light input and output are at the same side of the structure (Fig.2) leading to a U-turn like route of transmission.

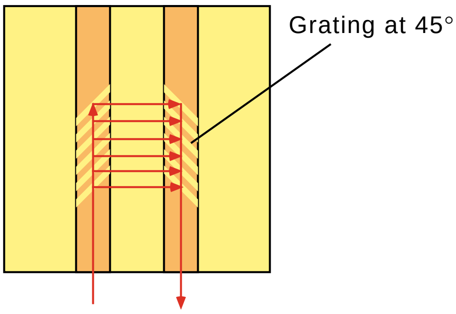

Figure 2: View from above on structure

2 Simulation

For simulation the structure is divided into cells with a border length of $\Lambda = \lambda$. λ is the wavelength of light inside the structure. Each cell comprises two transitions of SiGe/Si and Si/SiGe. For calculations the reflections of each transition must be combined to one reflection factor representing the reflections of a whole cell (Fig.3).

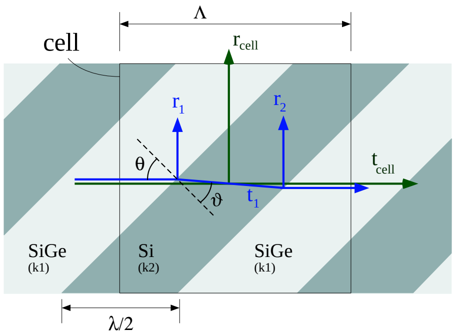

Figure 3: Reflections and transmissions within a cell

For calculating the reflection factor of the cell r_{cell} the continuity of tangential vectors at all transitions within the cell must be considered. After the first transition the cross section of the optical field is changed. Therefore the energy density related to the transmission t_1 is changed too. Considering all this the reflection factor of the cell r_{cell} can be expressed as

$$r_{cell} = \sqrt{\Gamma} \cdot [r_1 + r_1(1 - r_1^2)] \cdot e^{-j[\frac{\Lambda}{2}(k_1+k_2)+\frac{\pi}{2}]} \quad (1)$$

Where k_1 and k_2 are wave vectors of silicon germanium and silicon respectively. The cross section of the grating is much smaller than the cross section of the optical field. Therefore only a certain part of light deals with the grating itself. The confinement factor Γ describes the part of the power of the beam overlaping the grating. r_1 is the reflection factor of the first transition. The reflection factor r_{cell} is in the center of the simulation cell. Therefore a correction of the phase has to be considered. Together with the transmission factor t_{cell} which can be calculated from r_{cell} a cell can be described completely.

3 Simulation results

The simulations are done with variable lengths of gratings but constant width. The width is assumed to be 14 cells in all simulations. Looking at the output power P of the structure and it's dependency on the reflection factor r_{cell} (Fig.4) a steady rising function can be found. On the other hand high output power P can also be accomplished at low reflection factors r_{cell} by choosing a longer length of both gratings (Fig.4b).

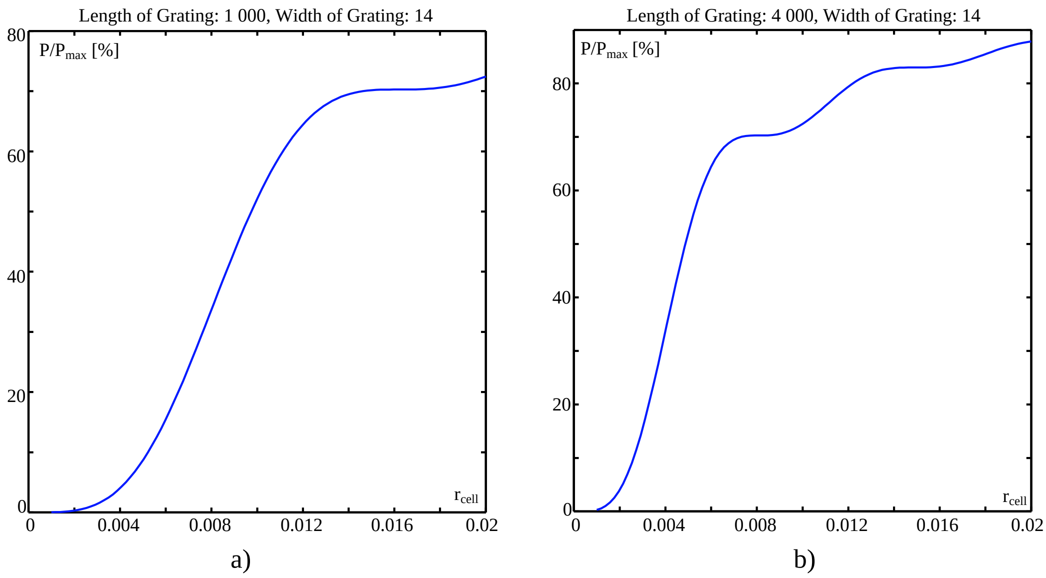

Figure 4: Related output power vs. refractive index given by simulation. The gratings are a) 1 000 cells and b) 4 000 cells in length respectively.

For all simulations a confinement factor Γ of 0.06 was assumed. This confinement is typical for our structure and results from waveguiding calculations [1].

As the layers of the structure are of p-Si/SiGe/n-Si it can also be used as a PIN diode, with an intrinsic layer of SiGe. Therefore free carriers can be injected into the SiGe layer lowering the refractive index. The change of the refractive index due to free carriers is [2]

$$\Delta n_{SiGe} = -\frac{N\lambda_0^2 e^2}{\epsilon_0 n_{SiGe} 8\pi^2 m^* c^2} \tag{2}$$

Here n_{SiGe} is the refractive index of SiGe at a free space wavelength λ_0, e is the electron charge, ϵ_0 is the permittivity of vacuum, m^* is the free-carrier effective mass, and c is the velocity of light.

Simulation results of two structures of different lengths and varied reflection indexes n_{SiGe} are shown in Fig.5. Looking onto the structure with grating lengths of 1 000 cells (Fig.5a) a high loss of power can be found at low refractive indexes n_{SiGe}. This shows that the lengths of the gratings are not optimised yet. The bandwidths are above $1nm$ but decrease with smaller values of n_{SiGe}.

The U-turn like route of transmission within the structure allows a number of possible transmission ways on which light can be guided through the gratings. The different routes vary greatly in length. A reduced reflection factor r_{cell} leads to a greater penetration into the gratings which opens more possible routes. The increased interferences result to reduced bandwidths. Bandwidths get smaller with decreasing reflection factors r_{cell} and increased lengths of both gratings. Gratings with lengths of 10 000 cells give a bandwidth of less than $0.1nm$ as shown in Fig.5b.

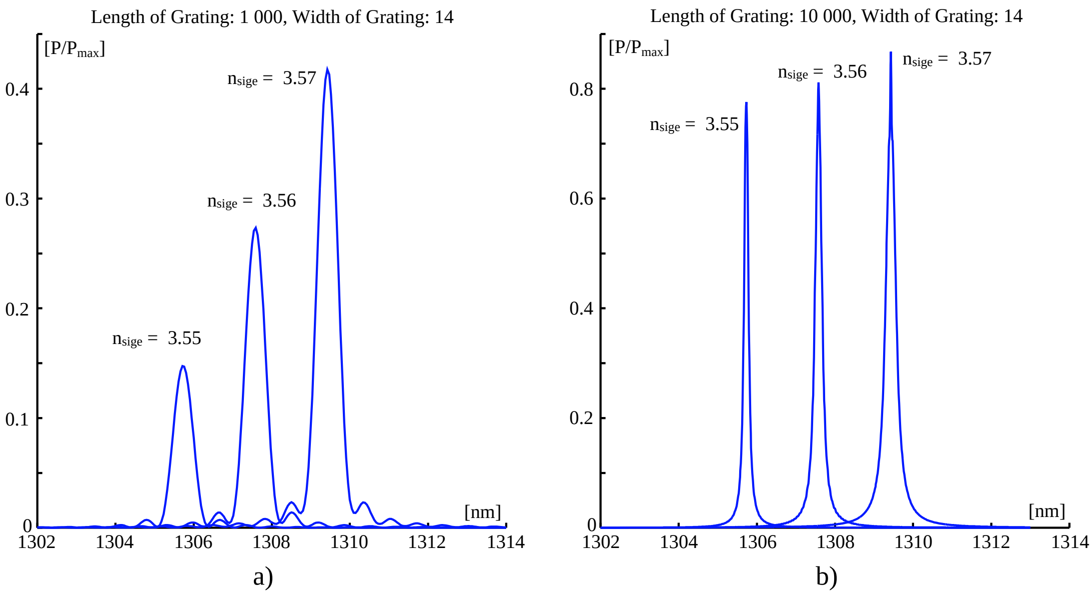

Figure 5: Related output power vs. free wavelength given by simulation. The gratings are a) 1 000 cells and b) 10 000 cells long. The refractive index of SiGe is varied from 3.57 to 3.55 in both cases.

4 Conclusion

With the here presented structure it is possible to get band-pass filters with bandwidths down to $0.1nm$. The bandwidth of a filter can be adjusted by the lengths of the gratings. By electronic displacement of the band pass region the structure can be used as an switch for the optical beam. The structure can be used to modulate a laser externally or to select one channel in a data communication system. Switching times are estimated down to the n-second range.

Acknowledgement

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References

[1] S.Boo, “Modeling of an Optical Ridge Waveguide with a Buried Layer in Si/SiGe System for Spectral Signal Processing”, in *SODC2000*, April 2000.

[2] E.Garmire, *Semiconductor Components for Monolithic Applications*, vol. 7, p. 244. Topics in Applied Physics, 1975.