Analysis of Biaxially Tensile Strained Ge/SiGe Multiple Quantum Wells for Electro-Absorption Modulators With Low Polarization Sensitivities

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Analysis of Biaxially Tensile Strained Ge/SiGe Multiple Quantum Wells for Electro-Absorption Modulators With Low Polarization Sensitivities

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Abstract: We analyze theoretically biaxially tensile strained Ge/Si0.18Ge0.82 multiple quantum wells (MQWs) for electro-absorption modulators with low polarization sensitivities. The difference between TE and TM polarized momentum matrix elements and absorption spectra are discussed. Our calculation indicates that polarization independent electroabsorption can be achieved by introducing 0.78% biaxial tensile strain in the buffer layer. The simulation results show that the maximum polarization independent absorption contrast ratio is 7.6 dB under 0 V/2 V operation at 1485 nm. The absorption contrast ratio is over 6 dB for both TE and TM polarizations with the wavelength ranging from 1467 to 1489 nm. The proposed scheme provides a promising approach to design highly efficient polarization independent Ge/SiGe MQWs electroabsorption modulators for on-chip optical transmission applications.

Index Terms: Multiple quantum wells, integrated optics devices, modulators, electro-optical devices.

1. Introduction

Silicon photonics is now the most attractive platform for photonic integrations [1]. Silicon-based modulator is a key component for silicon photonics. Over the last decades, much attention has been drawn to silicon modulators based on plasma dispersion effect, including micro-rings [2]–[3], Mach-Zehnder Interferometer (MZI) structures [4]–[6] and photonic crystals [7]–[8]. These silicon modulators are convenient for use on silicon-on-insulator (SOI) platform, and simple in construction. However, these silicon modulators rely on highly confined waveguides and precise resonance structures. As a result, they all require high precision manufacturing and complicated temperature controlling [9]. Another drawback of silicon modulators is the high polarization sensitivity caused by large structural birefringence.

Ge/SiGe multiple quantum wells (MQWs) electro-absorption modulators have shown advantages in aspects of low energy consumption and small footprint [10]–[11]. Strong quantum-confined Stark effect (QCSE) in Ge quantum well has been observed by experiments [10], but the operating wavelength range is limited. We proposed and analyzed electro-absorption modulators with uniaxially...
stressed Ge/SiGe MQWs in our previous work [12]. The use of suspended micro-bridge can tailor the absorption edge of Ge/SiGe MQWs, so the operating wavelength range is expanded. Uniaxially stressed Ge/SiGe MQWs has an enhanced TE mode absorption contrast and suppressed TM mode absorption. The polarization dependent absorption makes it inappropriate for polarization independent applications. This shortcoming can be eliminated by introducing biaxial strain. On the other hand, for the same amount of shift in bandgap energy, the biaxial strain required is much smaller than uniaxial strain [13]. The biaxial strain can be introduced by the suspended micro-bridge structure [14]–[17].

We analyze the absorption properties of biaxially strained 10/15 nm Ge/Si0.18Ge0.82 MQWs. By introducing 0.18%–0.96% biaxial tensile strain, zero-biased electro-absorption modulators covering 1380–1550 nm wavelength range can be fabricated. For zero-biased electro-absorption, only 2 V driving voltage is applied and no bias voltage is required. We also show that a maximum polarization independent absorption contrast ratio of 7.6 dB at 1485 nm wavelength under 0 V/2 V operation can be achieved by introducing 0.78% biaxial strain. The absorption contrast ratio is over 6 dB within 1467–1489 nm wavelength range for TE and TM polarizations.

2. Design of the Ge/SiGe MQWs and Suspended Micro-Bridge

Fig. 1(a) schematically shows our epitaxy design of a strain balanced Ge/Si0.18Ge0.82 MQWs structure. Theoretically, lower Ge content in the barrier is beneficial in increasing the quantum confinement which is critical for the QCSE effect. However, lower Ge content in the barrier means larger lattice mismatch between well and barrier. When the lattice mismatch is larger, improving the crystal quality of MQWs is more difficult. The barrier Ge contents of 0.8–0.85 have proven to be suitable for Ge/SiGe MQWs [11], [18]. In our design, we set the well width to be 10 nm as previous experiments have observed strong QCSE effect in 10 nm Ge well [10]. A 300 nm p-type Si0.15Ge0.85 buffer layer is grown on a [001] oriented Si substrate followed by ten pairs of 10/15 nm Ge/Si0.18Ge0.82 surrounded by 40 nm thick intrinsic Si0.15Ge0.85 spacers. Finally, the whole structure is capped by a 100 nm n-type Si0.15Ge0.85 layer which serves as the top contact.
Table 1
Parameters Used in the 3-D FEM Modeling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>SI</th>
<th>Ge</th>
<th>Literature reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic constants</td>
<td>C_{11}</td>
<td>165.77GPa</td>
<td>128.53GPa</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>C_{12}</td>
<td>63.93GPa</td>
<td>48.28GPa</td>
<td></td>
</tr>
<tr>
<td>Buffer Initial strain</td>
<td>ε_{xx}</td>
<td>0.18%</td>
<td></td>
<td>[20]</td>
</tr>
<tr>
<td>tensor</td>
<td>ε_{yy}</td>
<td>0.18%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ε_{zz}</td>
<td>-0.12%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1(b) and (c) show the micro-bridge structure and strain distribution simulated by using the COMSOL 3-D finite element method (3-D FEM), respectively. A linear elastic module is used in the 3-D FEM simulation. The elastic constants and the initial strain tensor in the buffer layer serve as input parameters, listed in Table 1. For SiGe alloys, the elastic constants are linearly extrapolated. From Fig. 1(c), we can see that the largest biaxial tensile strain is strongly located at the tip of the etching pattern. At the central area of the micro-bridge, the strain is uniform with desired biaxial tensile strain value. Our waveguide is situated at the central area where the strain is uniform. The accurate control of the strain at the central area requires that the 400 μm x 400 μm area to be fully suspended. Once the micro-bridge is totally suspended, the strain value changes very slowly with the size of the under-etch area providing a large fabrication tolerance. Otherwise, the strain value drops rapidly with the decrease of the under-etch area when the micro-bridge is inadequately suspended.

The strain balanced design is essential to obtain high quality crystal in a MQWs material growth. The lattice constant of the MQWs region matches with that of the buffer layer or substrate so that the MQWs region does not receive strain from the buffer layer below during the successive growth of the MQWs. Because there is 4% lattice mismatch between Si and Ge, direct epitaxies of Ge and Ge-rich SiGe alloys on silicon substrate are plagued by surface roughness and dislocations. It is necessary to grow a buffer layer on Si substrate followed by a high temperature anneal process [10], [18]. The anneal process induces 0.1%–0.3% tensile strain in the buffer layer when the wafer cools down. The residual tensile strain can be amplified by the fabrication of suspended micro-bridge structure which requires several steps of dry etching and wet etching. Experiments have proved the feasibility of fabricating under-etch structure in both bulk Ge and Ge/SiGe MQWs circumstances [17], [21]–[22]. The micro-bridge structure and the strain accumulation effect are detailed in [14]–[16]. The strain amplification factor on the bridge mainly depends on the shape of the etched area. For the 0.5% biaxially tensile strain microcross, the deviation of biaxial strain value between simulation and Raman spectroscopy was less than 0.1% [16]. Recent work on Ge/SiGe MQWs microdisks achieved 0.51% biaxial tensile strain and revealed the feasibility of tuning the strain in Ge/SiGe quantum wells [17].

3. Modeling of Ge/SiGe MQWs and Material Parameters

The theoretical models used in this calculation, including electronic band structures, polarization dependent absorption coefficient and QCSE of the strained Ge/SiGe MQWs are available in [12], [23]. The parameters are linearly extrapolated, listed in Table 2. The \( \Gamma \)-valley band structure is modeled by an 8 band \( k \cdot p \) model which shows excellent agreement with experimental results [19]. We get the absorption coefficient by combining the direct bandgap transition with the one-phonon modeled indirect bandgap absorption [19], [24]:
TABLE 2
The parameters at 300 K for Si and Ge used in the calculation of band structures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Si</th>
<th>Ge</th>
<th>Literature reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spin-orbit split energies</td>
<td>α</td>
<td>0.044 eV</td>
<td>0.289 eV</td>
<td>[19]</td>
</tr>
<tr>
<td>Average valence band energies</td>
<td>E\textsubscript{V,av}</td>
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<td>-6.35 eV</td>
<td>[25]</td>
</tr>
<tr>
<td>Bandgaps</td>
<td>E\textsubscript{g}</td>
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<td>0.7985 eV</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>E\textsubscript{g}</td>
<td>1.65 eV</td>
<td>0.664 eV</td>
<td>[26]</td>
</tr>
<tr>
<td>Deformation potentials</td>
<td>a\textsubscript{c}</td>
<td>-10.39 eV</td>
<td>-10.41 eV</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>a\textsubscript{v}</td>
<td>-0.66 eV</td>
<td>-1.54 eV</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>a\textsubscript{v}</td>
<td>1.8 eV</td>
<td>1.24 eV</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>-2.1 eV</td>
<td>-2.86 eV</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>-4.85 eV</td>
<td>-5.28 eV</td>
<td>[19]</td>
</tr>
<tr>
<td>Effective masses</td>
<td>m\textsubscript{c}</td>
<td>0.528 m\textsubscript{e}</td>
<td>0.038 m\textsubscript{e}</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>m\textsubscript{LL}</td>
<td>1.659 m\textsubscript{e}</td>
<td>1.57 m\textsubscript{e}</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>m\textsubscript{LL}</td>
<td>0.133 m\textsubscript{e}</td>
<td>0.0807 m\textsubscript{e}</td>
<td>[26]</td>
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<tr>
<td>DKK parameters</td>
<td>L</td>
<td>-6.69 \hbar^2/2m\textsubscript{e}</td>
<td>-31.3 \hbar^2/2m\textsubscript{e}</td>
<td>[27]</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>-4.62 \hbar^2/2m\textsubscript{e}</td>
<td>-5.9 \hbar^2/2m\textsubscript{e}</td>
<td>[27]</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>-8.56 \hbar^2/2m\textsubscript{e}</td>
<td>-34.14 \hbar^2/2m\textsubscript{e}</td>
<td>[27]</td>
</tr>
<tr>
<td>Indirect bandgap absorption parameters</td>
<td>Θ</td>
<td>320K</td>
<td></td>
<td>[24]</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>1150 cm\textsuperscript{-1}</td>
<td></td>
<td>[28]</td>
</tr>
</tbody>
</table>

\[
\alpha (\hbar \omega) = \frac{\pi q^2}{n_r c m_0^2 \omega L_w} \sum_{s,t} \int \int \frac{2dk_x dk_y}{(2\pi)^2} |\langle \Psi_s^k | \hat{p} | \Psi_t^k \rangle|^2 \cdot L \left[ E_{s,t}^{'\text{c,v}} (k) \right] \left[ f_s^c (k) - f_t^v (k) \right] + A \left[ \frac{1}{1 - e^{-\Theta/T}} \left( \frac{\hbar \omega - E_{g,\text{ind}} - k_B \Theta}{\hbar \omega} \right)^2 + \frac{1}{e^{-\Theta/T} - 1} \left( \frac{\hbar \omega - E_{g,\text{ind}} + k_B \Theta}{\hbar \omega} \right)^2 \right] (1)
\]

where q is the electron charge, n_r is the refractive index, c is the light speed in vacuum, m_0 is the free electron mass, \omega is the angular frequency, L_w is the well width. \langle \Psi_s^k | \hat{p} | \Psi_t^k \rangle is the momentum matrix element between s conduction-band state and t valence-band state of \Gamma-valley. The band structure of \Gamma-valley is modelled by an 8 band k.p model [19]. h is the Planck’s constant divided by 2\pi, L \left[ E_{s,t}^{'\text{c,v}} (k) \right] \left[ f_s^c (k) - f_t^v (k) \right] is the Lorentzian lineshape function and γ is the Lorentzian linewidth defined by Full-Width-at-Half-Maximum (FWHM), E_{s,t}^{'\text{c,v}} (k) are the state energies. f_s^c (k) and f_t^v (k) are the Fermi functions where k is the in plane wave vector. k_B is the Boltzman constant and T is the Temperature. For the indirect bandgap absorption, A is a temperature related constant, Θ is the equivalent temperature corresponding to the phonon energy, E_{g,\text{ind}} is the indirect bandgap. We set the temperature to be 300 K all through the calculations with a Lorentzian linewidth of 3 meV. The residual biaxial strain induced by thermal expansion in the buffer layer is assumed to be 0.18%. The unstrained lattice constant of Si1-xGex is determined by [29]

\[
\alpha_{Si_{x-1}Ge_x} = \alpha_{Si} + 0.01992x + 0.0002733x^2 (\text{nm}). (2)
\]
Analysis of Biaxially Tensile Strained Ge/SiGe MQWs

Fig. 2. Energy dispersions of $\Gamma$-valley electron subbands ($\Gamma e_1$, $\Gamma e_2$) and valence hole subbands (heavy hole HH1, HH2 and light hole LH1) on 0.18% biaxially strained buffer (dash lines) and 0.96% biaxially strained bridge (solid lines).

For Si$_{1-x}$Ge$_x$ alloys, the Dresslhaus-Kip-Kittel (DKK) parameters are determined by using the scheme in [27].

4. Theoretical Results and Discussions

4.1 Zero-Biased Electro-Absorption at 1550 nm Under Biaxial Strain

Recent research in biaxially tensile strained Ge/SiGe MQWs has confirmed an extended optical response beyond a wavelength of 1.5 $\mu$m [30]. But the absorption properties under different polarizations have not been discussed. In this section, we give a detailed discussion about the absorption properties of 10/15 nm Ge/Si$_{0.18}$Ge$_{0.82}$ on biaxially tensile strained Si$_{0.15}$Ge$_{0.85}$ buffer under different polarizations and voltages.

The energy dispersions along [100] and [110] directions are shown in Fig. 2. The lowest confined electronic subband states of $\Gamma$-valley ($\Gamma e_1$, $\Gamma e_2$, $\Gamma e_3$) and confined hole subband states (heavy hole HH1, HH2 and light hole LH1) are included. The bandgap of the 10 nm Ge well on 0.18% biaxially tensile strained buffer is 0.9 eV. The electron dispersions are close to parabolic with nearly constant effective mass for each subband under different biaxial tensile strains. We label the valence subbands as heavy hole and light hole subbands according to their $k// = 0$ characters for brevity. The valence band mixing effects significantly affect the optical transitions in the biaxially strained Ge/SiGe MQWs. The simulation results indicate that 0.96% biaxial strain is sufficient to reduce the direct bandgap energy to 0.8 eV which corresponds to the communication 1550 nm wavelength. The bandgap shrinkage of bulk Ge and Ge/SiGe MQWs under biaxial tensile strain were experimentally observed by previously works [30]–[31].

Fig. 3 shows the normalized momentum matrix elements of TE and TM polarizations. For our electro-absorption modulator configuration, TE mode corresponds to $y$ polarization, while TM mode corresponds to $z$ polarization. We focus on the $\Gamma e_1$-HH1, $\Gamma e_1$-LH1 and $\Gamma e_1$-HH2 transitions because they are dominant for the shape of the absorption edge. When the biaxial strain in the buffer layer is 0.18%, $\Gamma e_1$-HH1 and $\Gamma e_1$-LH1 transitions are allowed by selection rules in both TE and TM polarizations and $\Gamma e_1$-HH2 transition is prohibited by symmetry. However, the $\Gamma e_1$-HH1 transition of TM polarization is much smaller than that of TE polarization and is mainly distributed in off-center areas. The different distribution patterns of $\Gamma e_1$-HH1 transition of TE and TM are caused by the
selection rules, as discussed by previous works [12, 17]. We notice that the distribution patterns of $\Gamma_1$-HH1 transition of TE and TM polarizations are changed when we introduce 0.96% biaxial strain in the buffer layer. For TE polarization, the $\Gamma_1$-HH1 transition is suppressed especially at the zone center and along [100] direction. For TM polarization, the $\Gamma_1$-HH1 transition is greatly enhanced and centralized to the zone center. The $\Gamma_1$-LH1 transition is suppressed by the biaxial tensile strain for both TE and TM polarizations. Although the $\Gamma_1$-HH2 transition is forbidden by symmetry, there are still some transition peaks due to the admixture effect of LH1 and HH1 into HH2. It is interesting to notice that this effect is enhanced by tensile biaxial strain for TE polarization, as shown by Fig. 3(a). The enhancement of $\Gamma_1$-HH2 transition under TE polarization is also observed in biaxially tensile strained III-V quantum wells [32].

Fig. 4(a) and (b) show the TE and TM absorption coefficients under different applied voltages. The built-in electric field of the p-i-n junction is 16.9 kV/cm. The device works under 0 V/2 V operation for 1550 nm wavelength and we call it as zero-biased electro-absorption modulation. The exciton peaks
are caused by the intersubband transitions between conduction subbands and valence subbands. The locations of Γe1-HH1, Γe1-LH1 and Γe1-HH2 transition energies at Γ-point are marked by colored arrows. It should be noted that these locations may not coincide with exciton peaks because the momentum matrix elements have different distribution patterns and the energy dispersions are close to parabolic. When $\varepsilon_{bi} = 0.18\%$, the absorption edge of TM polarization is dominated by Γe1-LH1 transition. This exciton peak is actually a combination of Γe1-LH1, Γe1-HH1 and Γe1-HH2 transitions because both Γe1-HH1 and Γe1-HH2 transitions have transition peaks away from the zone center, shown in Fig. 3(b). In contrast, the absorption edge of TE polarization is dominated by Γe1-HH1 transition and the effects of Γe1-HH1 and Γe1-HH2 transitions are not obvious. As a consequence, the TE absorption edge comes at a longer wavelength and has a steeper slope than TM polarization. When $\varepsilon_{bi} = 0.96\%$, both TE and TM absorption edges are moved to the 1550 nm wavelength because of the bandgap shrinkage effect caused by biaxial tensile strain [30]. The absorption coefficients at the location of Γe1-HH1 exciton peak for TE and TM polarizations are calculated to be 1900 cm$^{-1}$ and 9500 cm$^{-1}$, respectively. As the size relationship between the absorption coefficients of TE and TM absorption edge is revised when $\varepsilon_{bi}$ is increased from 0.18% to 0.96%. It is reasonable to expect that there is a value of $\varepsilon_{bi}$ which allows the same absorption coefficient for both TE and TM absorption edges.

### 4.2 Polarization Independent Absorption at 1450 nm

Fig. 5 shows the normalized squared momentum matrix elements with various biaxial strains in the buffer layer. It is clear that Γe1-HH2 transition for TE polarization is enhanced by the biaxial tensile strain. The increase of the Γe1-HH2 transition strength results in a significant exciton peak near the absorption edge. The most important feature is that the Γe1-HH1 transition strength of TE polarization is suppressed by the biaxial tensile strain. In contrast, the Γe1-HH1 transition strength of TM polarization increases along with the biaxial tensile strain in the buffer layer. When $\varepsilon_{bi}$ changes from 0.6% to 0.8%, the Γe1-HH1 transition strength of TM polarization exceeds that of TE polarization. It should be mentioned that, the absorption coefficient at the absorption edge is a combination of Γe1-LH1, Γe1-HH1 and Γe1-HH2 transitions. They have different contributions under the increase of biaxial tensile strain in the buffer layer. So it is not enough to predict the absorption spectra accurately by observing the momentum matrix elements map only.

In order to obtain a polarization independent absorption, we calculate the absorption spectra under different biaxial strains. The absorption coefficients at the location of Γe1-HH1 exciton peaks are shown in Fig. 6. In general, the curves can be divided into three regions. When $\varepsilon_{bi}$ is smaller than 0.6%, TE and TM absorption coefficients increase slightly with the biaxial strain. From 0.6% to 1.1%, the absorption of TE polarization drops, while that of TM polarization increases. As a consequence, they intersect at around 0.78%. Over 1.1%, the growth of TM absorption coefficient tends to be saturated gradually.

Fig. 7(a) shows the absorption spectra under 0.18% and 0.78% biaxial strains. It is clear that the wavelength difference between TE and TM absorption edges disappears when $\varepsilon_{bi} = 0.78\%$. However, TE and TM absorption curves do not overlap as the corresponding transition patterns are quite different, as can be seen in Fig. 5. Fig. 7(b) shows the absorption contrast ratio under 0 V/2 V operation. The voltage swing can be reduced by increasing the quantum well width [23]. Under 0 V/2 V operation, the maximum absorption contrast is 6.3 dB and 7.4 dB for TE and TM polarization respectively when $\varepsilon_{bi} = 0.18\%$. By increasing $\varepsilon_{bi}$ up to 0.78%, we get a polarization independent maximum absorption contrast ratio of 7.8 dB at 1485 nm wavelength. Within 1467–1489 nm wavelength range, the absorption contrast ratio is over 6 dB for both TE and TM polarizations. The corresponding contrast ratio of the 16 µm device under 0 V/2 V operation is 8.5–9.7 dB. The maximum contrast ratio occurs at the wavelength about 1478 nm. Previous experimental works observed 9–15 dB extinction ratios with device length of 90–114 µm and overlap factor between light field and the MQWs region around 10% [33]–[34]. In this paper, the relatively high theoretical extinction ratio is owning to the large overlap factor around 38% and the enhanced absorption coefficients under tensile strain. The polarization independence of the device relies on the accurate control of
Fig. 5. Normalized squared momentum matrix elements for \( \Gamma e_1-HH_1 \) and \( \Gamma e_1-HH_2 \) transitions of TE (y polarization) and TM (z polarization): (a) \( \varepsilon_{bi} = 0.2\% \), (b) \( \varepsilon_{bi} = 0.4\% \), (c) \( \varepsilon_{bi} = 0.6\% \), (d) \( \varepsilon_{bi} = 0.8\% \).

the biaxial tensile strain. When the biaxial tensile strain is changed, for example decreased by 2%, the contrast ratio of TE and TM polarization are 10.2 dB and 9.0 dB for 1478 nm causing 1.2 dB polarization difference.

The length of the micro-bridge can be scaled up to 50 \( \mu m \) or even longer. All structural parameters should be scaled up correspondingly to achieve equivalent biaxial tensile strain in the central area. The decrease of biaxial tensile strain along the waveguide occurs near the edge of central area. With larger biaxial tensile strain, the absorption edge of central area locates at longer wavelength. The Stark shift under operation voltage also causes the absorption edge to move to longer wavelength. As a result, the decrease of tensile strain along the waveguide won’t dramatically decrease the contrast ratio or introduce extra insertion loss for a certain wavelength. It should be mentioned that the polarization independent absorption contrast can only be achieved within a limited wavelength range once the parameters of the Ge MQWs are settled. In our design, when \( \varepsilon_{bi} \) is larger than 0.78%, the TE absorption is overly suppressed at the absorption edge making the device unsuitable for TE mode modulation. Further design is required to achieve a polarization independent absorption at 1550 nm wavelength which is beyond the scope of this paper.
Fig. 6. The absorption coefficients at the location of $\Gamma e_1$- HH1 exciton peak under different biaxial strains.

Fig. 7. (a) Absorption spectra under 0.18% and 0.78% biaxial strains. (b) Absorption contrast ratio under 0 V/2 V operation.

5. Conclusion

We have proposed a design of Ge/SiGe MQWs electro-absorption modulators with low polarization sensitivities. Through analyzing the absorption properties of 10/15 nm Ge/Si0.18Ge0.82 multiple quantum wells on biaxially tensile strained Si0.15Ge0.85 buffer, we show that the absorption edge difference between TE and TM polarizations can be eliminated by bringing in 0.78% biaxial tensile strain into the buffer layer. The simulation results indicate that zero-biased electro-absorption modulators covering 1380–1550 nm wavelength can be achieved by introducing 0.18%-0.96% biaxial tensile strain into the buffer layer. Under 0.78% biaxial tensile strain and 0 V/2 V operation, we get a polarization independent absorption contrast ratio of 7.6 dB at 1485 nm. Within 1467–1489 nm wavelength range, the absorption contrast ratio is over 6 dB for both TE and TM polarizations. The proposed scheme provides a promising approach to design highly efficient polarization independent Ge/SiGe MQWs electro-absorption modulators for on-chip optical transmission applications.
References