Optical absorption and quantum efficiency in the resonant-cavity detector with anomalous dispersion layer

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Outline

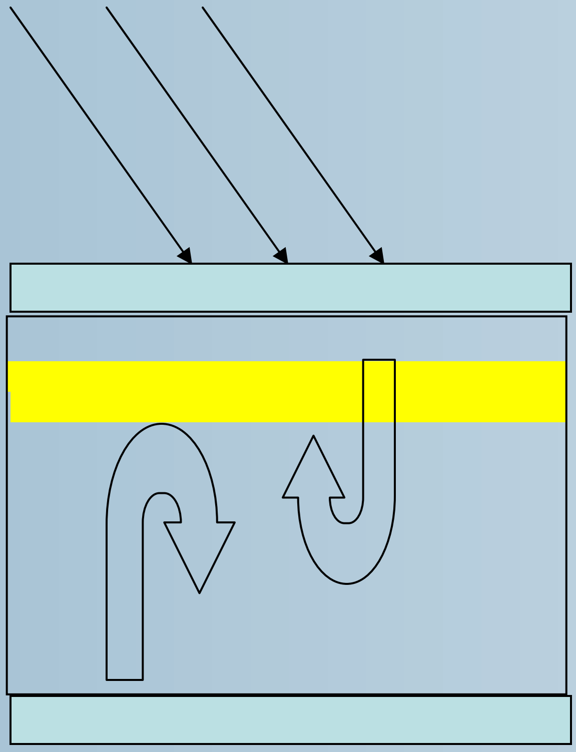
- Introduction
- Investigated structure
- Computation method
- Simulation results
- Conclusions

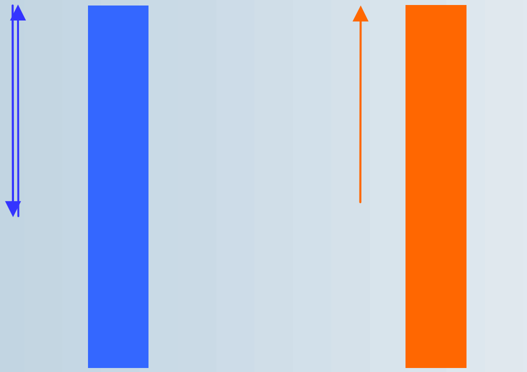
Photonics

The Ideal Photodetector

- **All the incident light would be absorbed**
- **The quantum efficiency would then be unity**
- Minimizing reflection at the incident surface;
- Maximizing the absorption within the depletion layer
- Avoiding recombination before the carriers are collected.

Resonant PD



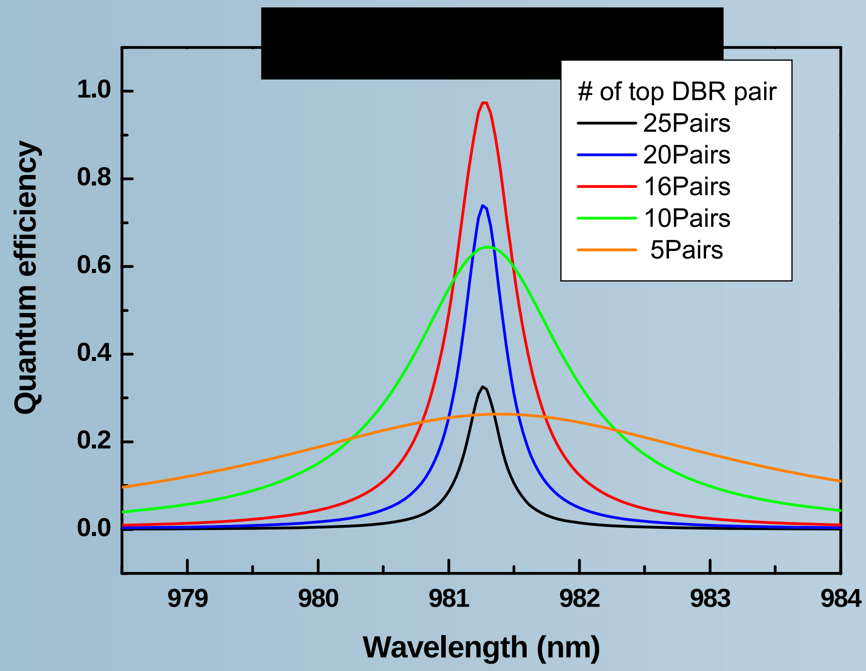


Quantum efficiency

Speed

Optimization of quantum efficiency

Quantum efficiency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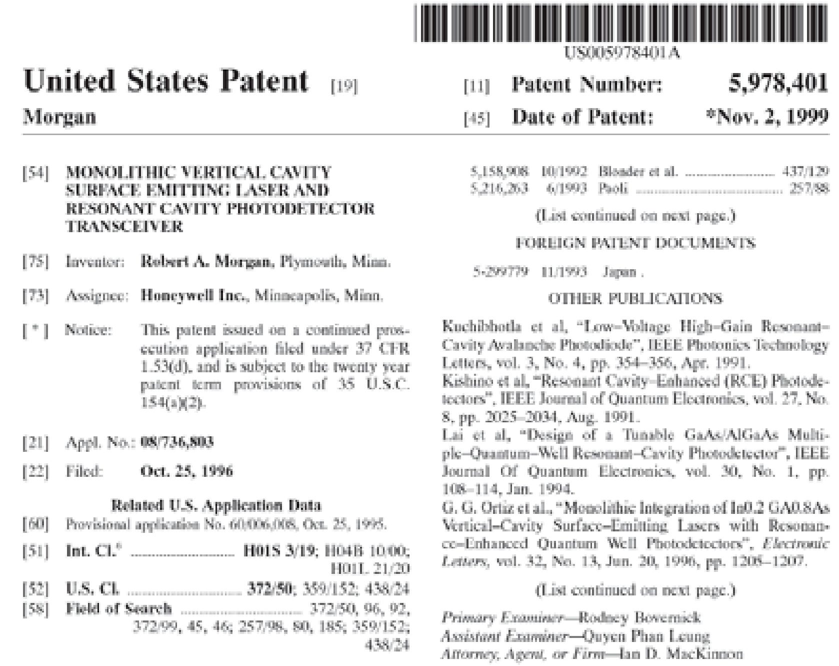
Quantum efficiency
= Absorbed Flux / Input Flux

- ✓ When number of layers in top DBR is chosen properly, quantum efficiency can reach almost 1.

$$r_{top} = r_{bottom} Exp(-\alpha d)$$

Even a slight mismatch of the cavity-mode wavelengths of paired VCSELs and RCE-PDs may considerably degrade the receiver sensitivity.

Patent on RCE&VCSEL integration transceiver



US005978401A

United States Patent [19]
Morgan

[11] **Patent Number:** **5,978,401**
[45] **Date of Patent:** ***Nov. 2, 1999**

[54] **MONOLITHIC VERTICAL CAVITY SURFACE EMITTING LASER AND RESONANT CAVITY PHOTODETECTOR TRANSCEIVER**

[75] Inventor: **Robert A. Morgan**, Plymouth, Minn.

[73] Assignee: **Honeywell Inc.**, Minneapolis, Minn.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **08/736,803**

[22] Filed: **Oct. 25, 1996**

Related U.S. Application Data

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[51] **Int. Cl.**^{6} **H01S 3/19**; H04B 10/00; H01L 21/20

[52] **U.S. Cl.** **372/50**; 359/152; 438/24

[58] **Field of Search** 372/50, 96, 92, 372/99, 45, 46; 257/98, 80, 185; 359/152; 438/24

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Kishino et al, "Resonant Cavity–Enhanced (RCE) Photodetectors", IEEE Journal of Quantum Electronics, vol. 27, No. 8, pp. 2025–2034, Aug. 1991.

Lai et al, "Design of a Tunable GaAs/AlGaAs Multiple–Quantum–Well Resonant–Cavity Photodetector", IEEE Journal Of Quantum Electronics, vol. 30, No. 1, pp. 108–114, Jan. 1994.

G. G. Ortiz et al., "Monolithic Integration of In0.2 GA0.8As Vertical–Cavity Surface–Emitting Lasers with Resonance–Enhanced Quantum Well Photodetectors", *Electronic Letters*, vol. 32, No. 13, Jun. 20, 1996, pp. 1206–1207.

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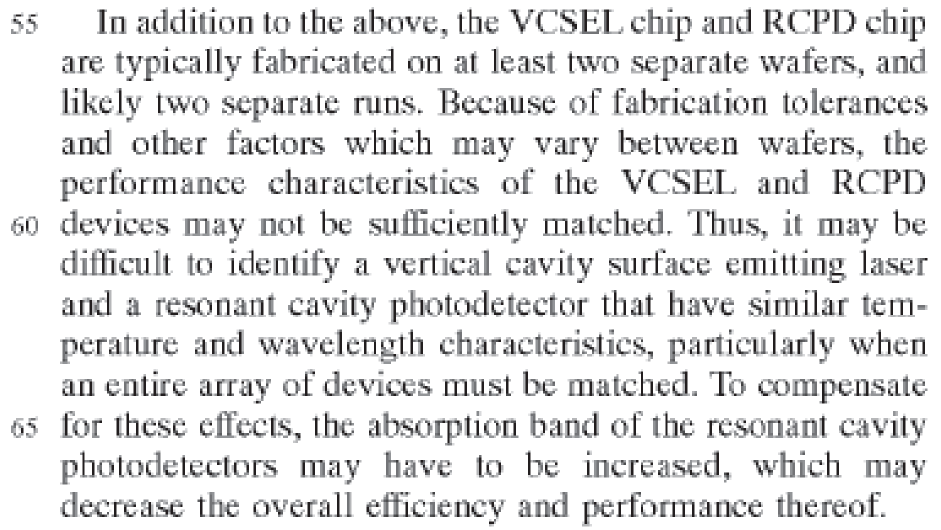
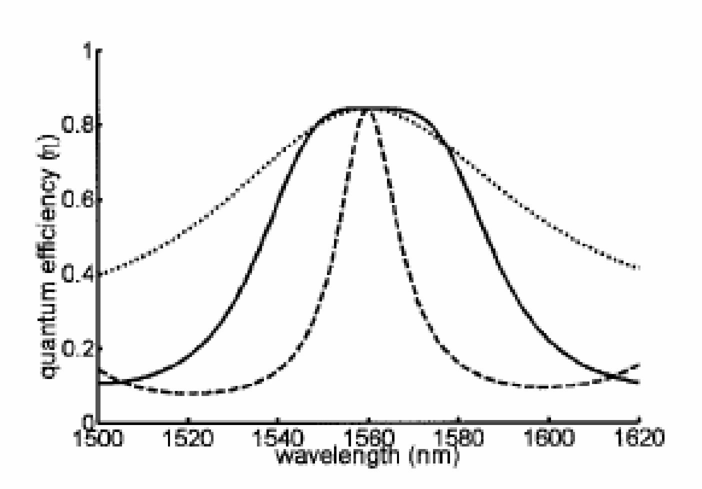


In addition to the above, the VCSEL chip and RCPD chip are typically fabricated on at least two separate wafers, and likely two separate runs. Because of fabrication tolerances and other factors which may vary between wafers, the performance characteristics of the VCSEL and RCPD devices may not be sufficiently matched. Thus, it may be difficult to identify a vertical cavity surface emitting laser and a resonant cavity photodetector that have similar temperature and wavelength characteristics, particularly when an entire array of devices must be matched. To compensate for these effects, the absorption band of the resonant cavity photodetectors may have to be increased, which may decrease the overall efficiency and performance thereof.

- **The broad band of absorption (and QE) spectra required**
- **The overall QE should be high**

QE flattop condition



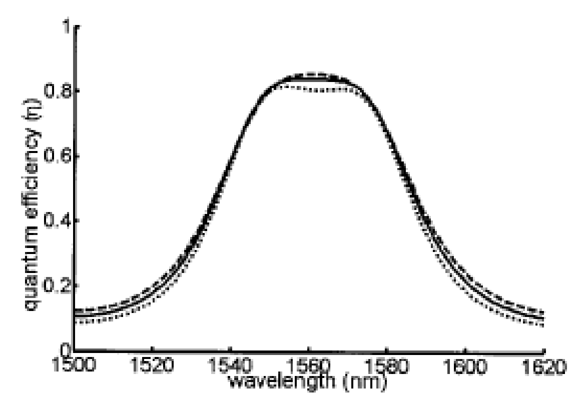
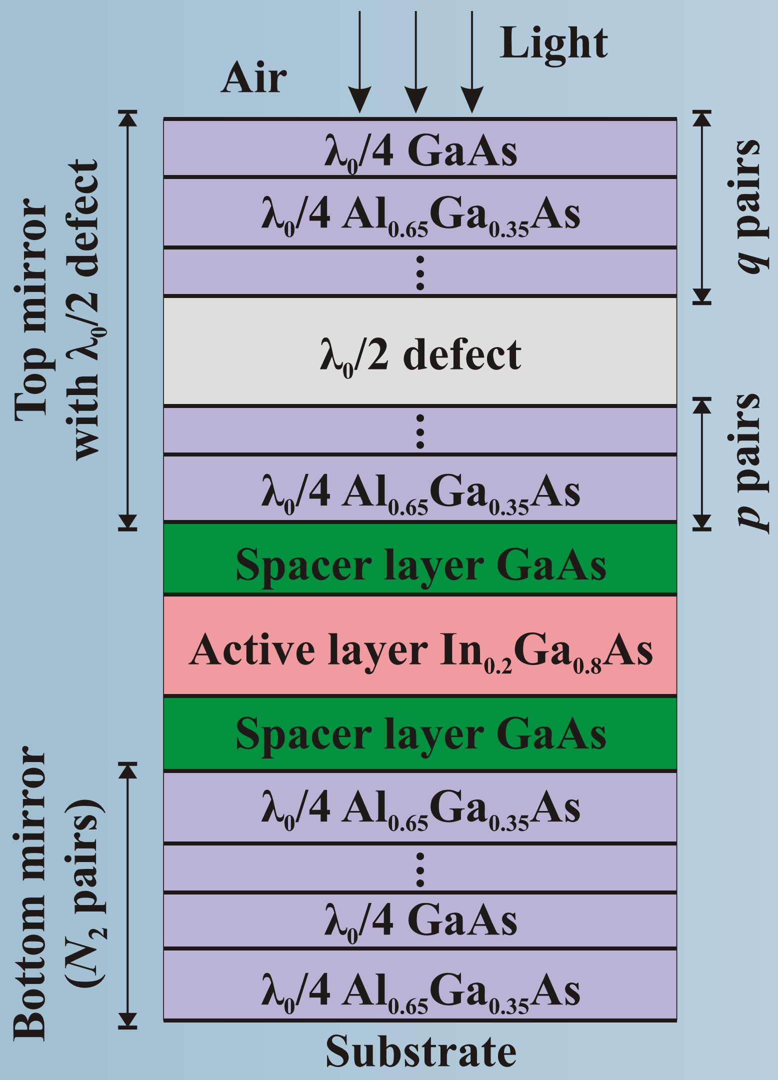


Fig. 6. Quantum efficiency versus absorption coefficient: $\alpha = 1.2 \times 10^4\ \mathrm{cm}^{-1}$ (dashed curve), $1 \times 10^4\ \mathrm{cm}^{-1}$ (solid curve), and $0.8 \times 10^4\ \mathrm{cm}^{-1}$ (dotted curve).

A resonant-cavity-enhanced photodiode with broad filter transmittance and high quantum efficiency was numerically designed and analyzed, fabricated, and validated experimentally.
Chen’s group show theoretically that the quantum efficiency spectrum broadens because of anomalous dispersion of the Reflection phase of a mirror in the device.

C.-H.Chen, K.Tetz, Y.Fainman, "Resonant-cavity-enhanced p-i-n photodiode with a broad quantum-efficiency spectrum by use of an anomalous-dispersion mirror," *Applied Optics,* 2005, Vol. 44, № 29, pp. 6131–6140.

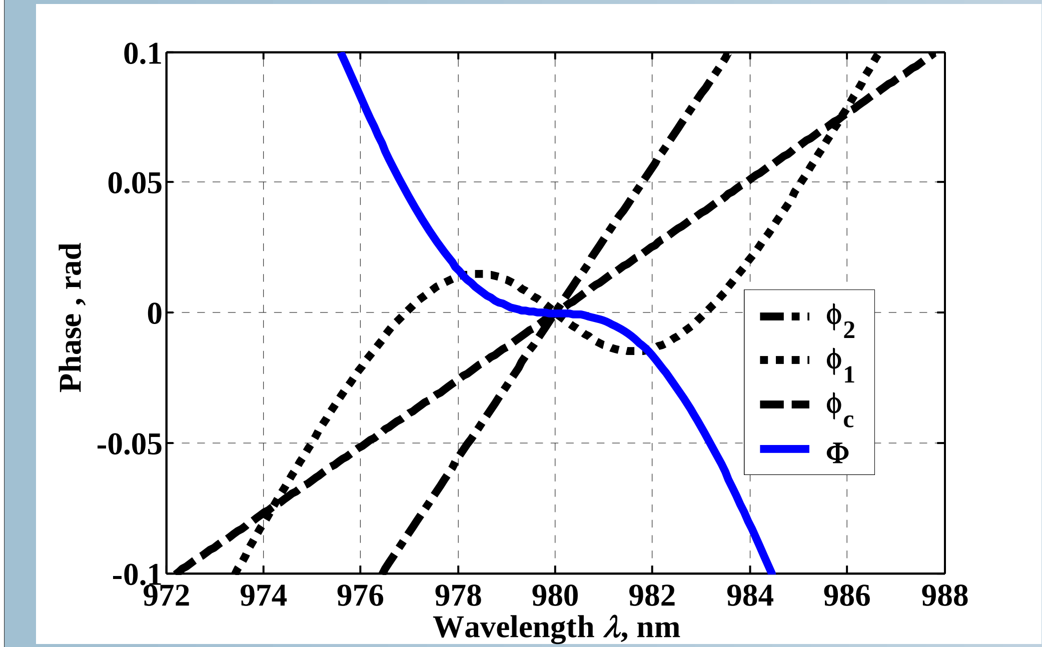
Investigated structure



Parameter	Value
Active layer thickness ($In_{0.2}Ga_{0.8}As$)	100 nm
Spacer layer thickness (GaAs)	88.2 nm
Index of GaAs	3.5256
Index of $In_{0.2}Ga_{0.8}As$	3.5691
Index of $Al_{0.65}Ga_{0.35}As$	3.1637
Free carrier absorption coefficient of active layer, ($In_{0.2}Ga_{0.8}As$)	$0.8\cdot10^4$ cm^{-1}

Reflection phase

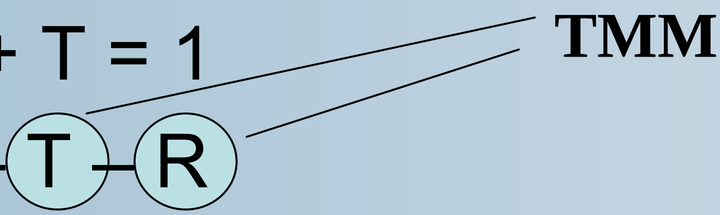
$$d\phi(\omega)/d\omega \approx 0$$



The reflection phase of the top mirror changes is abnormal near to a resonance.

By changing number of layers in the top mirror it is possible to achieve compensation of the phase variation of total phase caused by wavelength dependence Φ_c and Φ_2 in the certain wavelength range. In this wavelength range a total phase Φ will be close to 0.

Computation method



- $R + A + T = 1$
- $A = 1 - T - R$

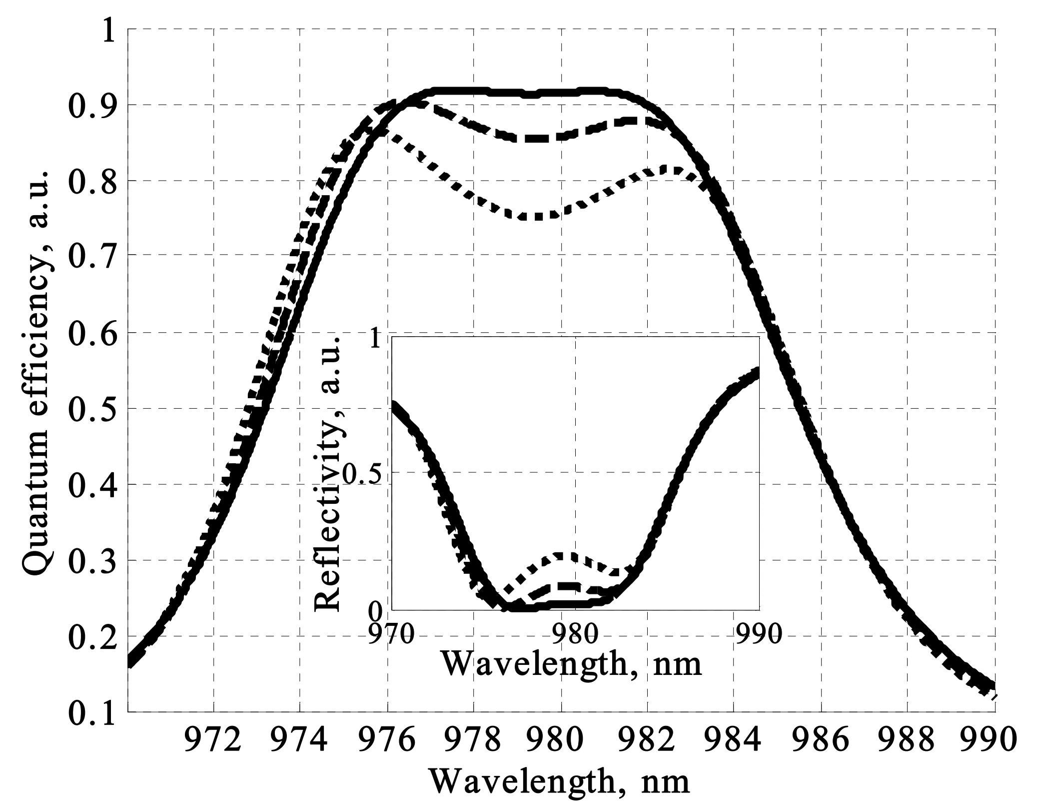
- $\eta = \eta_a \cdot \eta_b \cdot \eta_c$
- $\eta_a = A$

We neglect:

- scattering and diffraction of light
- consider only longitudinal distribution of waves
- absorption in mirrors and spacer layers

QE spectra of RCE PD

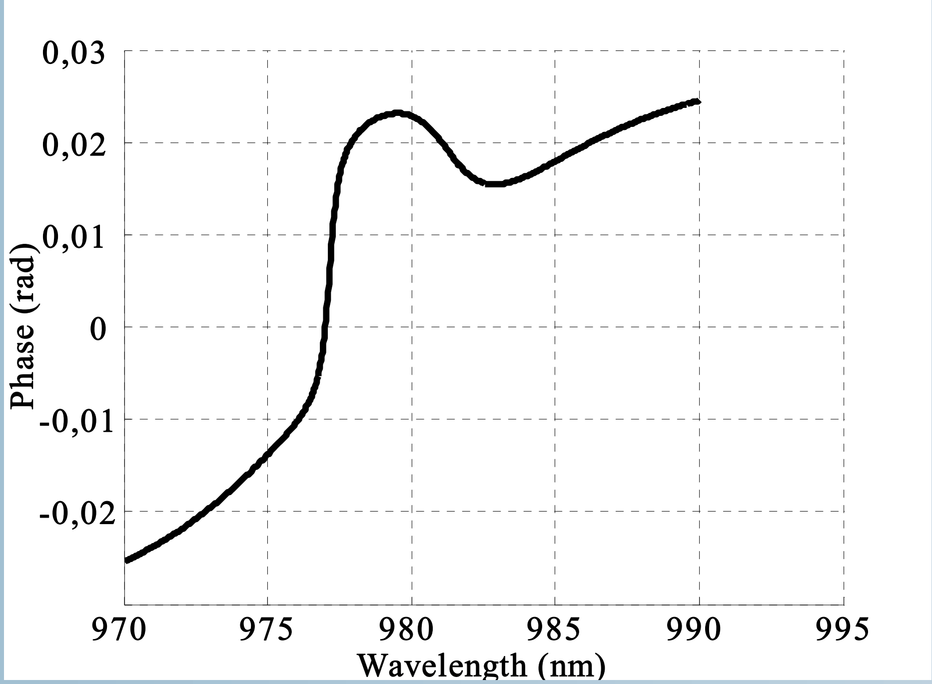
maximum QE of 92.5% and 6 nm flattop



- **Solid curve corresponds to q=1.5, p=11.**
- **Dashed and dotted corresponds to q=2.5 and q=3.5 respectively.**

Wavelength dependence of reflection phase shift

Data correspond to q=1.5, p=11.

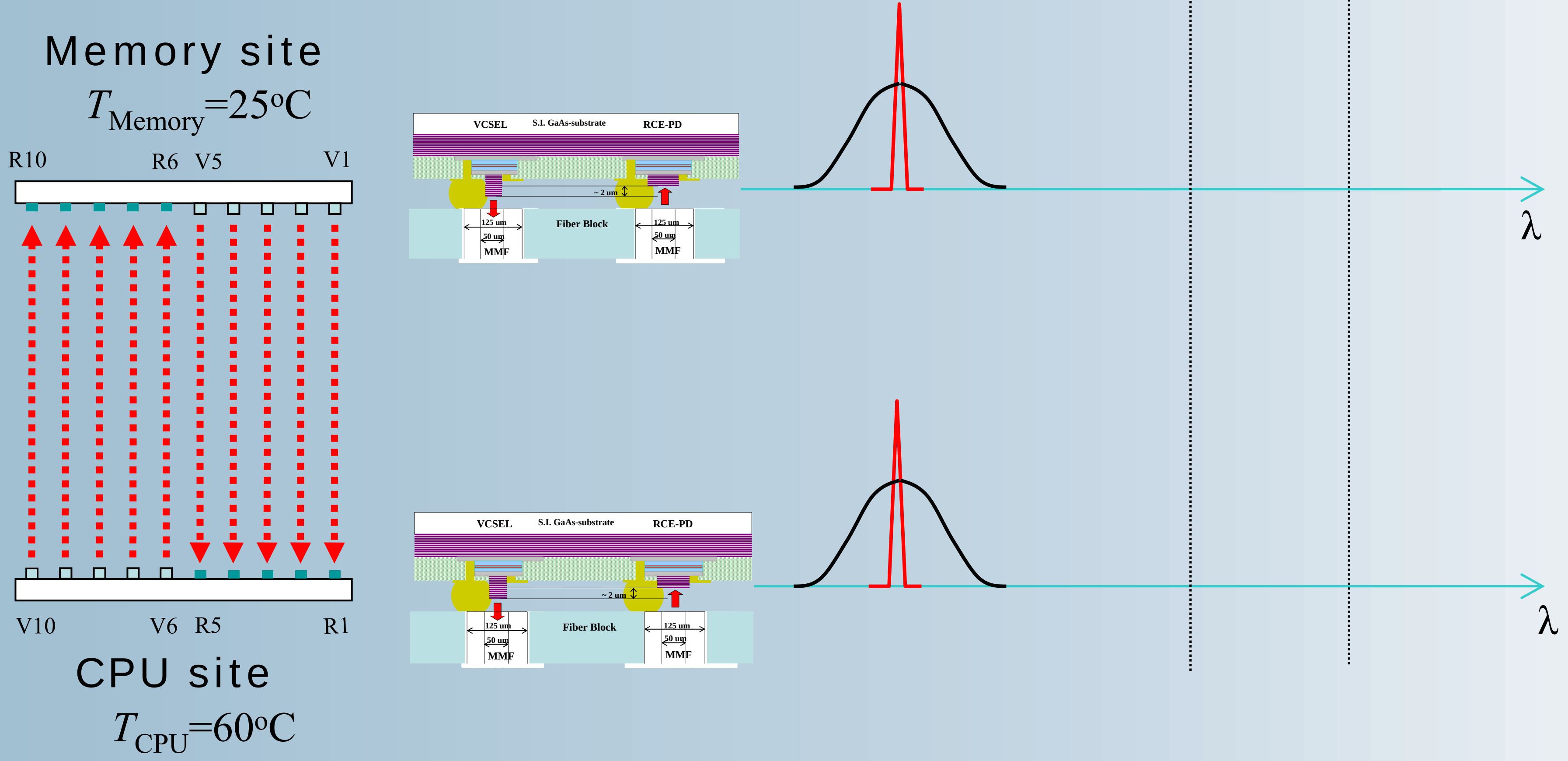


The reflection phase of the whole structure changes abnormal near to a both resonances in structure.

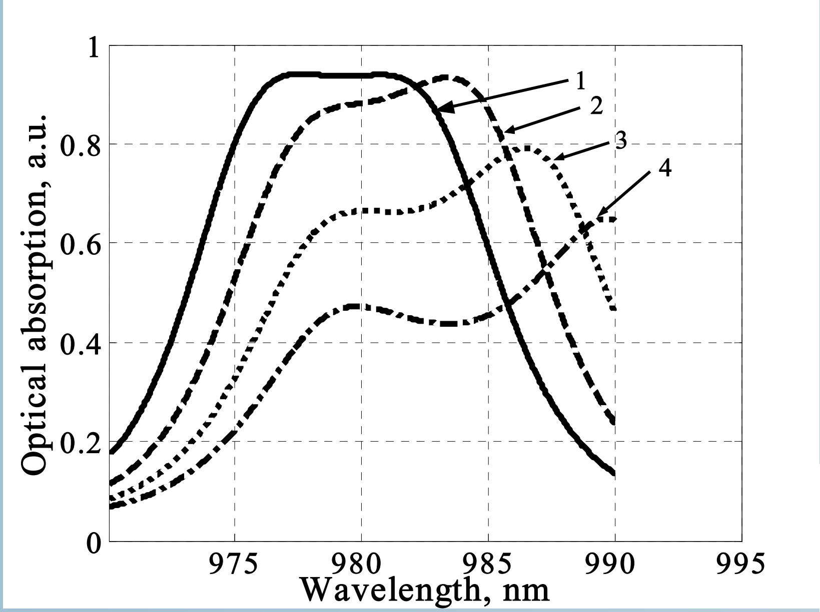
The flat-toped QE critically depends from the shape of the reflection phase curve in this region

Temp. dependence of cavity-mode λ for VCSEL and RCE-PD

- The mismatching of cavity-mode wavelength can be compensated by tuning the cavity-mode wavelength of RCE-PDs.



Optical absorption



Thickness of AD layer:

1- λ/2,

2-λ/2+10 nm,

3-λ/2+20 nm,

4-λ/2+30 nm

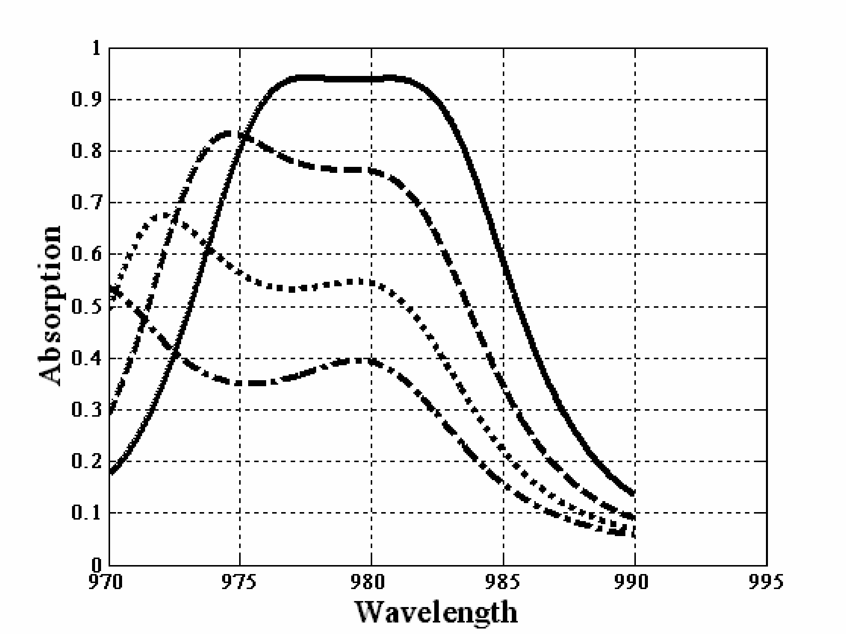
Thickness of AD layer:

1- λ/2,

2-λ/2-10 nm,

3-λ/2-20 nm,

4-λ/2-30 nm



Conclusions

- The increasing of the AD layer thickness up to 30 nm (6,12% for λ=980 nm) gives the amplitude reduction of absorption maxima more than 0.3 a.u. and leads to red shift of both observed peaks.
- By using an AD mirror in place of the DBR as top mirror we have achieved flattopped condition and high QE.

$$d\phi(\omega)/d\omega = 0$$

- For achievement flattopped the spectral response the additional condition should be satisfied.