

High-Speed High-Efficiency Photodetectors for Short Pulse Applications

M. Selim Ünlü, M. Gökkavas, and G. Ulu
Boston University, Photonics Center, 8 Saint Mary's St., Boston, MA 02215
Phone: (617) 353-5067, e-mail: selim@bu.edu

Richard P. Mirin, and David H. Christensen
National Institute of Standards and Technology, Boulder, CO 80303

Resonant cavity enhanced (RCE) photodetectors (PD) are promising candidates for applications where high-speed high-efficiency photodetection is desirable. In RCE devices, the active device structure is placed inside a Fabry-Perot resonant microcavity that causes a large enhancement of the resonant optical field. The increased optical field allows the design of thinner photodetectors while simultaneously increasing the quantum efficiency at the resonant wavelengths.¹ Hence RCE PD overcome the usual low-efficiency shortcoming of conventional transit time limited high-speed devices² and can typically provide much higher bandwidth-efficiency (BWE) products. Figure 1 shows measured quantum efficiency of RCE p-i-n photodiodes designed for near-unity quantum efficiency.³ The BWE product was in excess of 50GHz. Details of the device structure and high-speed measurements can be found in our former report.

In addition to the increased optical field at resonance, wavelength selectivity comes as a natural result of the Fabry-Perot cavity. Typically, quantum efficiency exhibits periodic peaks that have the shape of a Fabry-Perot transmittance. In general, the full-width-at-half-maximum (FWHM) of the resonance peak is used to describe the spectral response of RCE detectors. The FWHM depends on the finesse of the cavity and can be relatively broad for RCE detectors with thick absorbing layers. For example, for the responses shown in Figure 1, FWHM is around 15nm. When the spectral window for the highest performance of an RCE photodetector is considered, FWHM is no longer a direct measure. For some applications, it is desirable to have a flat top spectral peak along with high quantum efficiency.

We consider two applications, namely optical communications and quantum optical measurements employing pulsed lasers which would benefit from a wider peak response than that is readily accomplished using RCE detection. In optical communication systems, having a flat response window for the RCE detector reduces the wavelength stability requirements for the emitters. We have designed RCE PD to complement the high-performance vertical-cavity surface-emitting lasers (VCSEL) at 850nm wavelength. Commercial VCSEL typically have operation wavelength specified at 850 ± 10 nm. Another possible application for high BWE product RCE detectors is quantum optical measurements of the fluctuations and correlation of light beams. These measurements are limited by the quantum efficiency of the detectors used: employing sub-unity quantum efficiency detectors complicates information retrieval about the intrinsic quantum observables.⁴ In addition to perfect efficiency, fast temporal response is also necessary, as pulsed sources are widely used in order to enhance nonlinear interactions involved in these experiments. Typical sources employed in these experiments generate short, spectrally broad pulses that range from tens of fs to few ps. The spectral width of a ~ 100 fs laser pulse in the near-IR regime, for example, is ~ 10 nm. While it is possible to adjust the resonance wavelength of the RCE PD by surface recess (see Figure 1) after the device processing, it is more

desirable to design and fabricate detectors with about 10nm flat spectral peaks for these and other applications. In this work, we describe the issue of obtaining a flat spectral response for RCE detectors and demonstrate the approach on a GaAs/AlGaAs p-i-n PD design example. The concepts are directly applicable for other materials and wavelengths.

As mentioned earlier, the shape of the resonant peak is the outcome of the Fabry-Perot resonance between the two mirrors of the microcavity. Using computational tools, we examined the dependence of resonance condition on the magnitude and phase properties of the top mirror. In order to obtain a flat-top resonance, we designed a modified top mirror which has a reflectance and phase modulation that equalize the resonance peak. In Figure 2, we plot the quantum efficiencies of a detector with the modified top mirror and a standard RCE detector exhibiting near-unity quantum efficiency at resonant wavelength. A factor of 3 improvement in the width of the peak spectral response is evident in this graph. Actual layer structures of the flat-top devices and the modified top mirror, as well as theoretical and experimental results for GaAs/AlGaAs p-i-n PD designed for 850nm operation will be presented.

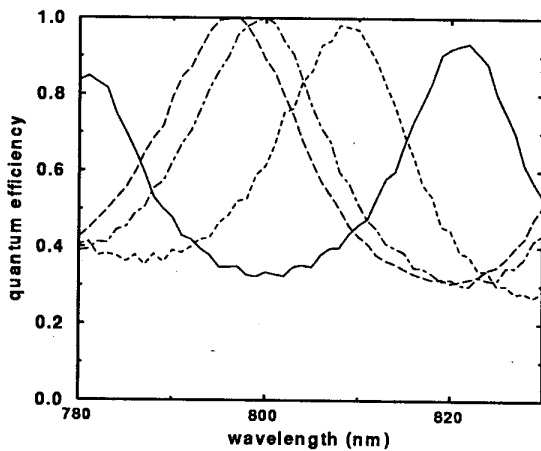


Fig.1 Measured quantum efficiency of near-unity efficiency GaAs/AlGaAs p-i-n PD for different recess etch steps.

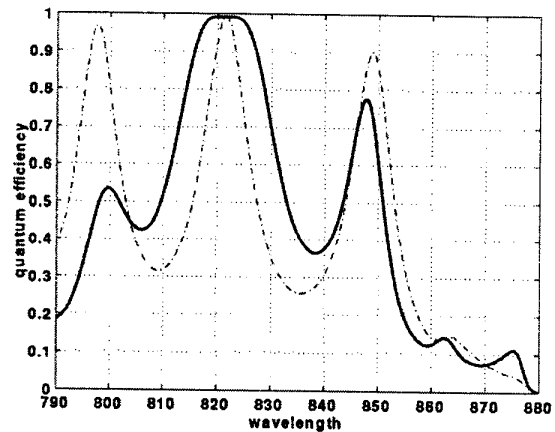


Fig. 2 The quantum efficiency of a near-unity efficiency RCE detector with(solid) and without(dashed) the modified top mirror.

REFERENCES

1. M. S. Ünlü and S. Strite *J. Appl. Phys.* **78**, pp. 607-628, 1995.
2. J. E. Bowers and C. A. Burrus *IEEE J. Lightwave Technol.* **5**, pp. 1339-1350, 1987.
3. E. Özbay, N. Biyikli, I. Kimukin, O. Aytür, M. Gökkavas, G. Ulu, R. P. Mirin, D. H. Christensen, K. A. Bertness, and M. S. Ünlü *Appl. Phys. Lett.* **74**, pp. 1072-1074, 1999.
4. O. Aytür and P. Kumar *Phys. Rev. Lett.* **65**, pp. 1551-1554, 1990.