# Resonant Cavity Enhanced Photodiodes with a Broadened Spectral Peak

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Resonant cavity enhanced (RCE) photodetectors (PD) are promising candidates for applications where both high speed and high efficiency are desirable. In such PDs, electrical properties remain mostly unchanged, but the optical response is modified strongly. At resonance, the quantum efficiency (η) of an RCE PD is drastically enhanced [1], enabling faster, transit-time limited PDs with thinner absorbers resulting in a larger bandwidth-efficiency product (BWE) than that achieved by conventional PDs utilizing a single-pass absorption scheme [2]. In the case of an RCE PD, spectral shape of the quantum efficiency resembles the transmission of a Fabry-Perot cavity. The width of the resonance peaks is expressed by the full-width at half-maximum (FWHM), determined by the finesse of the cavity [1]. Even when the finesse is low, resulting in a large spectral width, η is a strong function of wavelength, decreasing significantly as the operating wavelength deviates from the resonance wavelength. In most applications, on the other hand, detection is performed in a spectral window, rather than at a single wavelength, which suggests that the effective BWE improvement achieved by RCE is less than the enhancement at the peak wavelength. The driving force of high-speed PD research is optical communications. To fully benefit from the RCE scheme in communications, the resonance of the detector has to match the source wavelength. Although it is possible to adjust the peak wavelength of an RCE PD during growth or fabrication processes, once finalized, this sets a constraint on the wavelength regime where the PD can be effectively used. Furthermore, fluctuations in the source wavelength cause the efficiency to fluctuate accordingly, therefore it is more desirable to be able to design the PD such that it can achieve peak enhancement for all wavelengths in a particular communication window. One application where high-performance RCE PDs can be employed is in short-distance communications complementing 850 nm vertical-cavity surface-emitting lasers (VCSEL) [3]. Commercial VCSEL manufacturers specify the emission wavelengths of these devices to be within a ~ 20 nm window centered around 850 nm [4]. To complement such devices, the PD has to sustain peak efficiency over the same wavelength range. Another application where the spectral shape of η is critical is when the device is used to detect ultrashort pulses with a broad spectral content. For example, the spectral width of a ~ 100 fs laser pulse in the near-IR regime is ~ 10 nm. To the best of our knowledge, there has been only one attempt to alter the shape of the response peak of an RCE PD in the past [5]. In that work, the authors' motivation was wavelength demultiplexing, where they were interested in the rejection of non-resonant wavelengths. Their structure requires illumination through the substrate side. Previously, we analyzed the introduction of a $\lambda/2n$ defect into a top distributed Bragg reflector (DBR) to achieve a flatter and wider peak [6]. In this letter, we describe a novel top mirror design and present experimental results.

The modification to the RCE scheme is as follows: By forming a secondary cavity adjacent to the PD cavity as shown in Fig. 1and coupling the optical field built in the secondary cavity to the PD cavity, the absorption at slightly off-resonance wavelengths is increased.

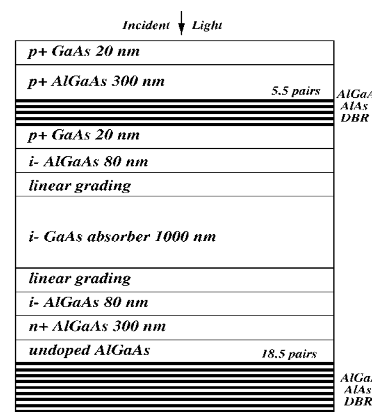


Fig. 1. Layer structure for the flat peak sample

The quantum efficiency at resonance is not increased proportionately since the feedback from the PD cavity to the secondary cavity is less at the center wavelength. The net result over a 10 - 20 nm window is an equalization of the quantum efficiency as shown by the simulations in Fig. 2. The shortcoming of the approach in [6] was that once the structure was grown, the resonance wavelength of the secondary cavity could not be adjusted since the defect layer was deep within the top DBR. The structure shown in Fig. 1 utilizes the air-semiconductor interface as one of the mirrors, therefore the secondary-cavity resonance is adjustable by a simple recess etch. Figure 3 shows the reflectance of the secondary cavity.

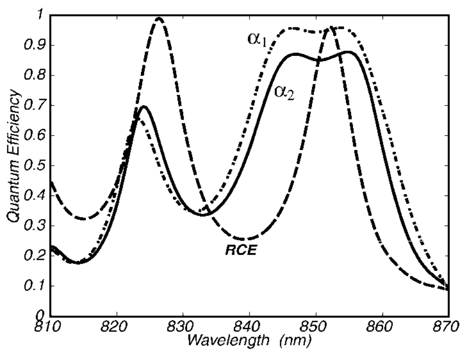


Fig. 2. Simulations of η for the flat-peak sample. The two curves correspond to two different values of α: $\alpha_1 d = 0.9$, and $\alpha_2 d = 0.7$.

An equally valid visualization is to consider this cavity between the top-DBR and the air-semiconductor interface as a mirror with a wavelength dependent reflectance. The flatness of the quantum efficiency peak is due to the fact that the reflectance is optimized for slightly off-resonance wavelengths. The dip in the reflectance curve in Fig. 3 that allows for an optimization for off-resonance wavelengths is a result of the resonance condition of the secondary cavity (the AlGaAs layer between the top DBR and the air-semiconductor interface). Figure 4 shows the spectral response of fabricated devices for the flat-top sample, and a standard RCE sample. The resonance wavelength of the flat-top sample was 840 nm, and that of the standard sample was 850 nm. The two curves are offset horizontally for clarity in Fig. 4. The width of the quantum efficiency peak at the 90% of the peak value was 15 nm for the flat-top sample, and 7 nm for the standard sample. The discrepancy between the shape of the simulations and the experimental result are believed to be due to a difference between the expected and actual values of the top DBR reflectance.

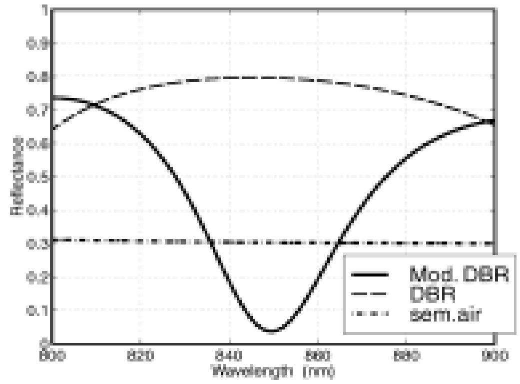


Fig. 3. Reflectance of the semiconductor-air interface, a DBR, and the modified DBR (secondary cavity) incorporating a 5.5 period DBR and a spacer.

We have fabricated and tested the high-speed response of RCE photodiodes with similar electrical structure. Based on these measurements we expect a transit-time limited 3 dB bandwidth of approximately 40 GHz. In conclusion, we have designed, fabricated, and characterized a novel RCE PD that exhibits a wider and flatter peak quantum efficiency when compared with a standard RCE PD. Unlike conventional RCE devices, these devices that have increased tolerance to wavelength variations can be used in short haul optical communications complementing VCSELs.

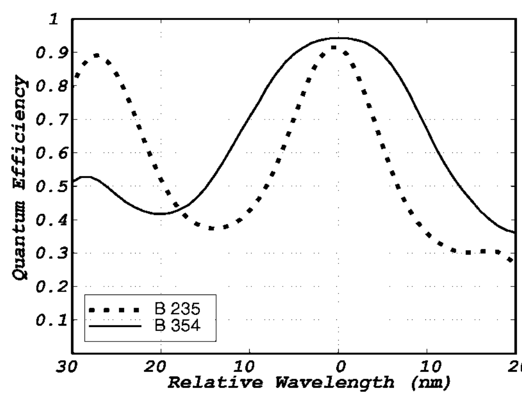


Fig. 4. Measured quantum efficiency for the sample in Fig. 1 (B354) and a standard RCE sample (B235).

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