Stuart Figure 1. Upper portion shows both the nanoparticle-SOI (silicon-on-insulator) sample geometry and a scanning-electron-microscope (SEM) image of a layer of Ag nanoparticles with mean particle diameter \( D = 108 \text{ nm} \). The SEM image includes a 1 \( \mu \text{m} \) scale bar. Lower portion shows plots of the measured photocurrent enhancement as a function of the illumination wavelength \( \lambda \) for three values of \( D \): (a) \( D = 40 \text{ nm} \), (b) \( D = 66 \text{ nm} \), (c) \( D = 108 \text{ nm} \).

Guide modes are excited, they propagate in all directions parallel to the Si surfaces until either rescattered or absorbed, in the latter instance increasing the measured photocurrent. That the enhancement increases with the mean particle diameter \( D \) supports this interpretation: the radiative efficiency of a Ag nanoparticle increases with diameter. The mechanism described here is a general one that can almost certainly be used with other thin photodetectors, but the technological importance of the SOI system makes these results particularly intriguing.

Acknowledgments

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High-Speed Resonant Cavity Enhanced Photodiodes

M. Selim Ünlü, Ekmel Özbay, Elias Towe, Richard P. Mirin, and David H. Christensen

A n important figure of merit for photodetectors used in optical communications is the bandwidth-efficiency (BWE) product. The quantum efficiency of conventional detector structures is governed by the absorption coefficient of the semiconductor material, meaning that thick active regions are required for high quantum efficiencies. Thick active regions, however, limit device bandwidths because of the long transit times of the photogenerated carriers. To optimize the BWE product it is desirable to enhance the quantum efficiency without increasing the active layer thickness. During the past decade, a new family of optoelectronic devices has emerged in which the performance is enhanced by placing the active device structure inside a Fabry-Perot resonant microcavity. In these Resonant Cavity Enhanced (RCE) structures, photodiodes benefit from the large increase of the optical field at the resonance wavelength of the cavity. The RCE photodetector can be thinner and therefore faster with enhanced quantum efficiency at resonant wavelengths.

We studied top illuminated RCE photodiodes in the InGaAs/GaAs/AlAs \(^2\) and AlGaAs/GaAs/AlAs \(^3\) material systems. Molecular beam epitaxy and standard photolithographic techniques were used in the fabrication of distributed Bragg reflector bottom mirrors and active layers of the detectors. Devices are defined by mesa isolation and an Au air-bridge connects the top contact to a co-planar transmission line. Figure 1(a) shows a SEM picture of a typical small area Schottky photodiode. The top reflector of the RCE structure is the Schottky metal itself, allowing the resonant wavelength to be adjusted during the fabrication by recessing the top semiconductor surface before depositing the metal. The resulting structure is a low loss cavity for a spectral region approximately 50 nm wide. In these devices the position of the

Ünlü Figure 1(a). SEM picture of the RCE Schottky photodiode.

Ünlü Figure 1(b). Measured pulse response displaying a 10 ps pulse width.
absorption layer in the depletion region is optimized to yield minimum transit time for electrons and holes.

The RCE Schottky photodiodes with InGaAs absorption regions in GaAs/AlAs microwires have been designed for 900 nm wavelength. These devices yielded a measured pulse width of 10 ps (Figure 1(b)). Considering a 9 ps FWHM for the 50 GHz scope, the device speed was estimated to be 4.3 ps corresponding to more than 10 GHz 3 dB bandwidth. Recently, we have demonstrated RCE Schottky photodiodes with GaAs absorption regions in AlGaAs/AlAs microcavities. The resonant wavelength can be adjusted in the 800-850 nm wavelength region, complementing efficient vertical-cavity surface-emitting lasers for short-distance optical communications applications. These devices demonstrate a peak quantum efficiency of 0.5 and a 3 dB bandwidth of more than 50 GHz. The BWE product exceeds 25 GHz. The RCE pin photodiodes, also wavelength adjustable around 800 nm wavelength range, have demonstrated 50 GHz BWE product and near unity quantum efficiency.

References

Fiber Gratings

All-Fiber Fourier-Transform Spectrometer
Mark Froggatt and Turan Erdogan

Optical fiber phase gratings fabricated in the core of a fiber by ultraviolet irradiation are critical components for optical communications and sensor applications. Most applications utilize fiber gratings as narrow-band reflection filters. However, fiber gratings are basically no different than any other diffraction grating, and as such they may also couple light out the side of the fiber. Simply put, the angle of the out-coupled radiation, \( \alpha \), measured in air with respect to the normal of the fiber axis, is related to the wavelength of light \( \lambda \) and the period of the grating \( \Lambda \) by \( \sin \alpha = n_{\text{eff}} \lambda / \Lambda \), where \( n_{\text{eff}} \) is the effective refractive index of the fiber mode. Since the angle is dependent on wavelength, a simple spectrometer can be made by directly measuring the out-coupled intensity versus angle in the far field.\(^1\) Wagener et al. demonstrated such a device with excellent performance using a chirped fiber grating to focus the light through an index-matched prism onto a linear detector array.\(^2\)

Here we show it is possible to simplify spectral measurement with a fiber grating by the elimination of all bulk-optical components and free-space alignment. In this approach the out-coupled radiation may be measured directly on the cladding of the fiber, making for a highly compact device. Rather than measuring the far-field (focused) radiation, the interference pattern formed between counter-propagating out-coupled beams is measured directly. Monochromatic light produces a sinusoidal pattern, while polychromatic light produces the Fourier transform of the spectrum. This device is well-suit for use as a high-resolution wavelength meter, an in-line or terminal network spectrum monitor (analogous to Reference 2), and a unique tool for \textit{in situ} analysis of the fabrication process or post-fabrication testing of very long fiber Bragg gratings with demanding specifications, such as those used for dispersion compensation.

The spectrometer is comprised of a fiber grating, an in-line reflector (such as an air-gap or fiber Bragg grating) to produce the counter-propagating beam, and a detector array either near or in optical contact with the surface of the fiber (see Figure). For in-line applications, the reflector need only reflect a small fraction of the light; for terminal applications a cleaved fiber end is suitable. The light on the detector array is the superposition of the radiation traveling in both directions. We have demonstrated this concept using a standard fiber Bragg grating designed to reflect light at 1545 nm.\(^3\) The same grating couples light out of the fiber perpendicular to the fiber axis at a wavelength of about 780 nm. Using a cleaved fiber end for the reflector, the inset in the figure shows the interference patterns produced by a tunable, single-frequency diode laser adjusted to the four different wavelengths indicated in the figure legend, measured on a CCD array near the fiber surface. The respective (1-D) Fourier transforms of these patterns are plotted in the figure. The peak wavelengths agree exactly with the wavelengths measured on a calibrated wavelength meter. The noise is mainly caused by extraneous interference fringes due to the CCD camera window and lack of optical contact with the fiber. Nevertheless, this demonstration illustrates how such a simple device is capable of a high resolution measurement.

References