Building and Characterizing 14GHz InGaAs Fiber Coupled Photodiodes

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Abstract:

A method to actively align the 50μm diameter core of a multi-mode fiber to the 40μm diameter active area of a 14GHz InGaAs photodiode was developed. A fixture was designed to launch a λ=1.3μm, 100MHz rep-rate sub-picosecond FWHM laser pulse stream into the fiber and monitor the photodiode output while adjusting the relative alignment of the fiber, a relay lens and the photodiode active area. The bandwidth and responsivity of the detector were determined from the impulse response function. The fiber coupling technique maintained the 14GHz bandwidth capability of the photodiode and achieved a Beta (electron charge out, to photon energy in) ratio of 0.38 Coulombs per Joule. The intrinsic Beta of InGaAs, by comparison, is 0.95 Coulombs per Joule at λ=1.3μm.

Motivation:

The bandwidth of a measurement system is limited by its slowest component. At LLE, measurements using pulsed lasers are typically made with 6GHz photodiodes and oscilloscopes. Recently, oscilloscopes with bandwidths in excess of 6GHz have become common. The 14GHz detectors will eventually replace the 6GHz detectors currently used to make most oscilloscope-based measurements. In particular, measurements made using 7GHz oscilloscopes will benefit from these faster detectors. When a 6GHz detector is used with a 7GHz oscilloscope, the combined bandwidth is lower than 7GHz. A 14GHz detector allows measurements to be made closer to the full bandwidth capability of the oscilloscope.

There is another measurement niche for the 14GHz detector. Streak cameras are used at LLE to make the highest bandwidth measurements. These streak cameras are orders of magnitude larger, heavier, and more expensive than a photodiode and an oscilloscope. Their size and weight make streak cameras less accessible to every part of the laboratory. In addition, the expense and complexity of using streak cameras limits their availability. A 14GHz detector and a fast oscilloscope are an adequate substitute for all but the most bandwidth-demanding measurements. For example, fast rise-time and temporally shaped laser pulses are adequately characterized with a 14GHz detector and a 7GHz oscilloscope when adjusting the laser that generates the shaped pulses. However, the final measurement to qualify shaped pulses for OMEGA is still made with streak cameras.

Design Objective:

The objective was to build a palm-size, 9V battery-powered, 14GHz InGaAs detector with an FC fiber input receptacle and an SMA electrical output connector that could be coupled directly to an oscilloscope. In addition, it was desirable to image couple the fiber output to the detector active area. This would allow the flexibility of using a wide variety of fibers to deliver light to the detector. The ratio of electron charge output from the detector to photon energy launched into the fiber, called the responsivity or Beta of a detector, of 0.33 Coulombs per Joule was set as a reasonable goal.

Primary Components Used in the Design:

Figure 1 is an exploded view of the primary components of the 14GHz detector. The enclosure has been omitted for clarity. The 14GHz photodiode is supplied mounted to the backside of an electrical SMA connector with a bias resistor and terminals for applying a bias voltage. The photodiode was covered with a 200μm thick transparent epoxy layer to protect the 40μm diameter active area. An FC style receptacle was selected to take advantage of the FC standard which supports both multi-mode and single fibers along with angle-polished and polarization-maintaining fibers. A molded glass aspheric lens was chosen to image relay, with a magnification of less than one, the 50μm diameter fiber output to the 40μm diameter photodiode active area.

The Detector Design and Assembly:

A fixture was designed and built to hold the photodiode stationary while the FC receptacle and the imaging lens could be moved together, in three dimensions, using micrometer-driven stages. By launching a pulsed laser into the fiber and monitoring the photodiode output with an oscilloscope, the micrometer stages could be moved until the best signal was obtained. The photodiode mount and the FC receptacle were soldered to either side of a brass mounting bracket making the FC mount, the relay lens and the photodiode mount a single rigid detector assembly (Figure 2). The detector assembly was mounted in a custom-designed enclosure that contained the bias battery and safeguarded the detector from being damaged when handled. The combination of fixtures and real-time alignment was an effective method to accurately align the image of the fiber output to the active area of the photodiode.

Detector Performance: Data Acquisition

The sub-picosecond laser pulse stream used to actively align the detector assembly also provided the excitation source needed to measure the detector's impulse response. Since the Fourier spectrum of a sub-picosecond pulse has equal energy frequency components well past 14GHz, the detector's response to this pulse contains the information needed to determine the detector's gain as a function of frequency. This is a very detailed method to measure bandwidth. By measuring the average energy of each laser pulse and the charge that flowed through the detector, the Beta of the detector was also calculated. The instrumentation setup used to capture the impulse response of the detector, to measure the average energy of each laser pulse and to determine the charge that flowed through the detector is shown in Figure 3.

Detector Performance: Data Analysis

A software program was developed to analyze the impulse response function of the 14GHz detector to determine its bandwidth. The analysis technique is based on the principle of superposition, which states that an arbitrary signal can be constructed from a summation of sinusoidal signals of the proper amplitude and frequency. The Fourier transform of a time varying signal is exactly this set of frequencies and amplitudes. Since a sub-picosecond laser pulse excites the detector, with equal energy, at all frequencies well above 14GHz, the amplitude of each Fourier frequency is a relative measure of the detector's gain at that frequency. Bandwidth is defined, by convention, to be the frequency at which the gain of a detector is 3dB below its gain at zero Hertz, also called the D.C. response. Figure 4 shows the time domain impulse response of the detector and its Fourier transform, called the frequency response of the detector, with a vertical line drawn at the frequency of the –3dB amplitude point.

Detector Performance: Bandwidth

Characterizing the response of a detector with a single parameter, in this case bandwidth, is useful when the objective is to simply sort detectors based on speed. When using a detector to accurately measure the bandwidth of another system, or device, it is necessary to know the full frequency response of the detector. If left uncorrected, the variation of gain, with frequency, of the 14GHz detector, as seen in Figure 4, would bias the results from measurements using this detector. This variation of gain with frequency can be removed from the measured response of a system under test by the additional application of Fourier techniques.

Detector Performance: Responsivity (Beta)

The responsivity of the detector was calculated as the ratio of electron charge conducted by the detector per pulse to photon energy per pulse launched in the fiber. The electron charge per pulse was calculated by integrating the impulse response function and dividing by the 50Ω load resistance of the oscilloscope. The average energy per laser pulse was calculated by dividing the average laser power by the laser pulse rate. The 14GHz detector assembly has a Beta (Coulombs/Joule) of 0.38. The intrinsic Beta of InGaAs photodiodes is 0.95 Coulombs/Joule. The reduced responsivity was probably caused by the image of the 50μm fiber overfilling the 40μm active area of the photodiode. The fixture did not allow for adjustment of the relay lens relative to the fiber output. This could result in the 50μm fiber being imaged with a magnification greater than one onto the 40μm photodiode active area. This would overfill the active area and reduce the responsivity. In addition, the protective, transparent, epoxy lump covering the active area of the photodiode was of poor imaging quality and probably prevented the fiber image from coming to a sharp focus, further reducing the optical coupling efficiency.

Conclusion:

All of the design objectives of the project were achieved. The 14GHz inherent bandwidth of the photodiode was preserved with the alignment, assembly and packaging approached used. The fiber input to the detector was through an FC type fiber coupler and was image relayed onto the 40μm active area of the photodiode. The responsivity of the detector, calculated as the ratio of electron charge conducted through the detector to photon energy injected into the fiber, of .38 exceeded the .33 design requirement.

Acknowledgments:

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Figures:

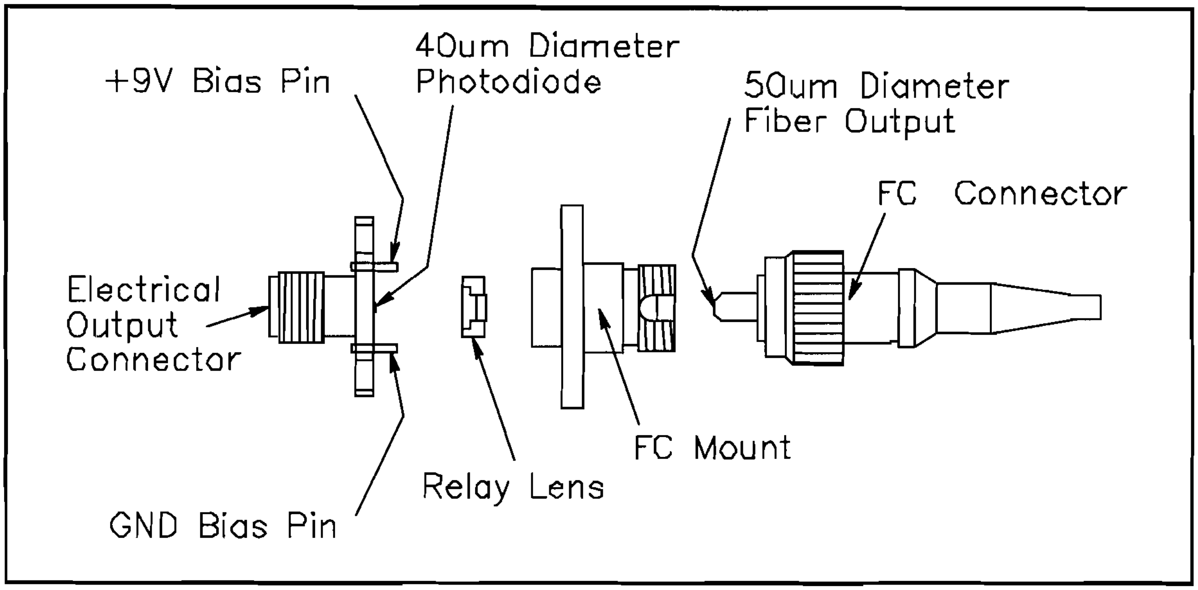

Figure 1.
An exploded view of the primary components of the 14GHz detector is shown. Laser light is delivered by a fiber optic terminated by the FC connector. Once assembled and aligned, laser light emitted from the 50μm diameter fiber is imaged by the relay lens onto the 40μm active area of the photodiode. The electrical output connector is attached to an oscilloscope to read out the signal.

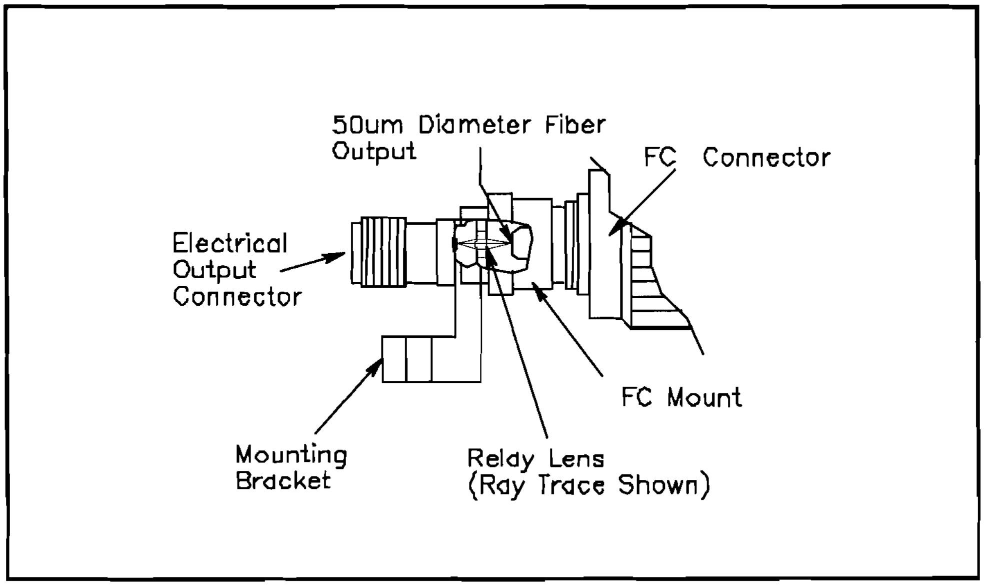

Figure 2.
A cutaway view of the assembled detector is shown. The mounting bracket is the mechanical "bridge" between the electrical output connector, which holds the photodiode, and the FC mount, which holds the relay lens. When the FC mount and electrical connector are aligned to produce the best signal, the FC mount, the mounting bracket, and the electrical connector are soldered together creating a rigid monolithic detector assembly.

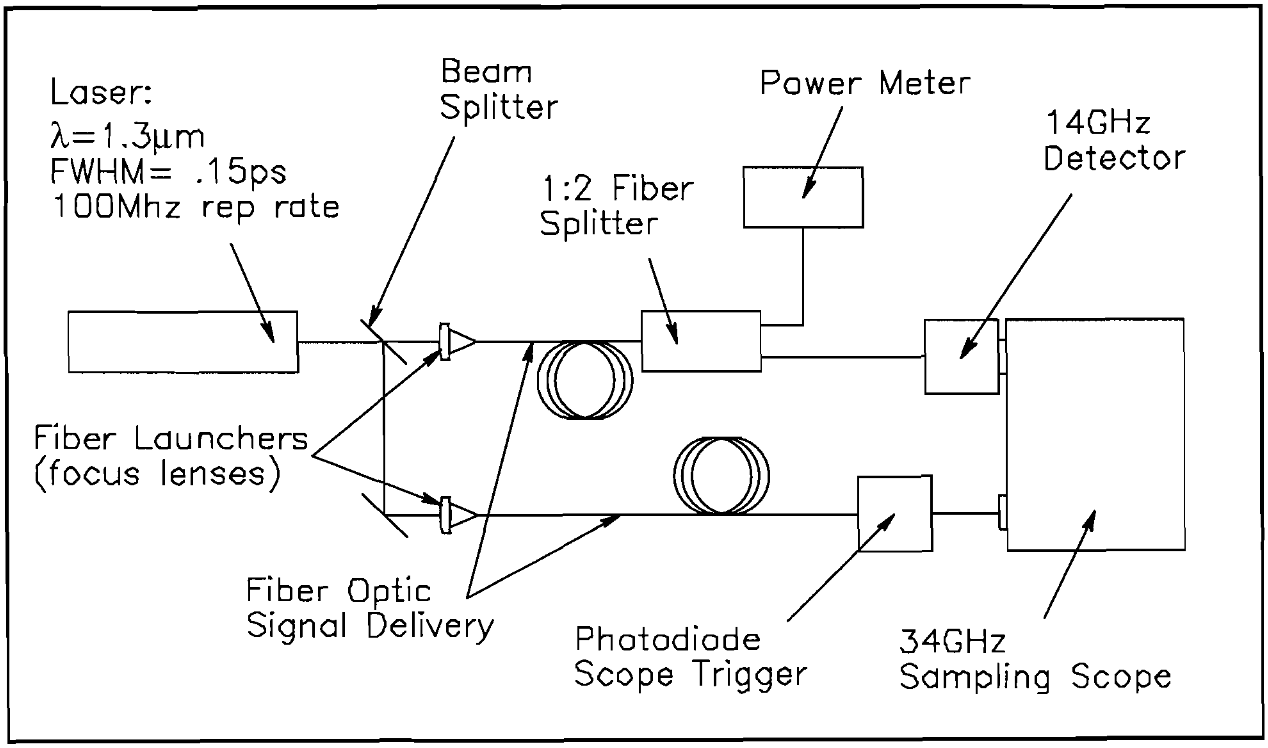

Figure 3.
The experimental setup used to capture the impulse response of the 14GHz detector and determine the average energy per laser pulse. A 100MHz rep-rate laser is split into two beams and launched into separate fibers. The first fiber is split into two branches. One branch measures the average power of the laser, the other branch delivers the pulse stream to the 14Ghz detector. The second fiber goes directly to a photodiode used to trigger the 34GHz sampling scope.

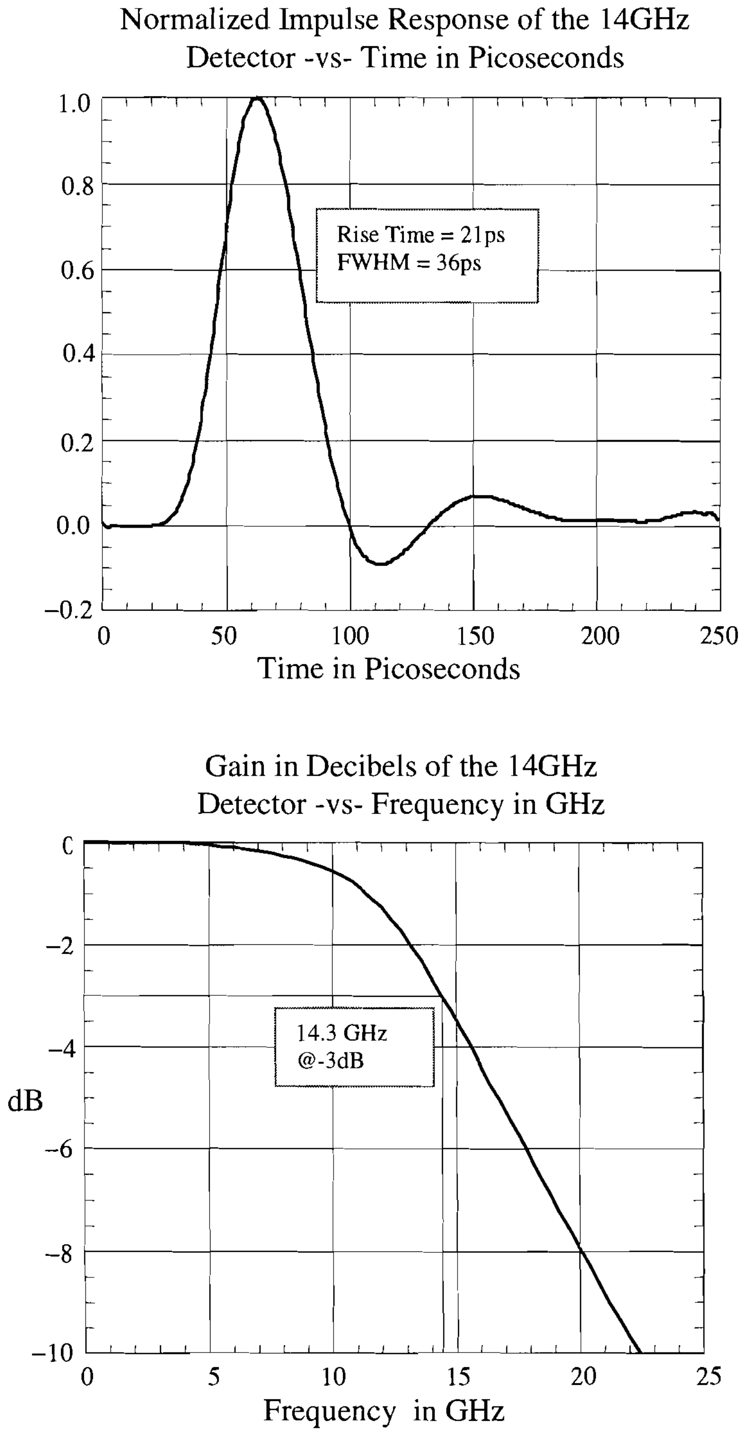

Figure 4.
The normalized response of the detector to a sub-picosecond pulse is shown in the top figure. The 21ps, 10% to 90%, rise time is consistent with the 14GHz expected bandwidth. The lower figure is the frequency response obtained from the Fourier transform of the impulse response. A frequency of 14.3GHz is indicated at the –3dB gain point. This frequency, by convention, is called the bandwidth of a detector.