Large Aperture Multiple Quantum Well Retromodulator for Free-Space Optical Data Transfer

G.C. Gilbreath
Remote Sensing Division

W.S. Rabinovich
Optical Sciences Division

Introduction: Free-space optical communications has emerged in recent years as an attractive alternative to the conventional radio frequency (RF) approach. This evolution has been due to the increasing maturity of lasers and compact optical systems, which enable exploitation of the inherent advantages of the much shorter wavelengths characteristic of optical and near-infrared carriers. These advantages include: large bandwidth, low probability of intercept, immunity from interference or jamming, frequency allocation relief, and in many cases, smaller, lighter payloads that, in turn, enable more compact, covert communications systems. For a conventional optical link, a good-to-high quality telescope that provides relatively accurate pointing and tracking capability is needed. Also needed is a robust laser with sufficient power, temperature stabilization, and requisite electronics, in addition to the usual modulating and demodulation and control and acquisition instrumentation and software. There are many applications, however, where reducing the parasitic payload requirements for the onboard communications system would be advantageous.

One such approach makes use of a simple optical corner cube coupled with a fast shutter to enable compact covert communications by reducing the payload's power, space, and weight requirements to nominal levels. Until relatively recently, however, no material existed that could support data rates on the order of a megabit per second and higher with efficiency and compactness. The Naval Research Laboratory has been developing a semiconductor electro-absorptive shutter for this purpose using multiple quantum well (MQW) technology.[1] This paper describes this device, including recent demonstrations of an infrared data link between a small rotary-wing unmanned airborne vehicle and a ground-based laser interrogator.

Wide Aperture Multiple Quantum Well Modulators: Semiconductor multiple quantum well (MQW) technology is the basis for commercially available laser diodes. When used as a shutter, MQW technology offers many advantages. It is robust and all-solid state. In addition, it operates at low voltages (less than 20 volts) and low power (less than 1 watt). Most importantly, it is capable of very high switching speeds (Fig. 6). MQW modulators have been run at data rates in the gigabits per second regime in fiber applications. The MQW modulators used in this program were grown at NRL by molecular-beam epitaxy (MBE) and have been shown to support a bit error rate of at least 10^{-6} at data rates of 10 megabits per second and higher.[2] The details of the growth and some optimizations used to improve the material quality are discussed in Ref. 3.

Briefly, the modulators consist of about 100 very thin (~10 nanometers) layers of several semiconductor materials, such as GaAs, AlGaAs, and InGaAs, epitaxially deposited on a large (3-inch diameter) semiconductor wafer. Electrically, they take the form of a P-I-N diode. Optically, the thin layers induce a sharp absorption feature at a wavelength that is determined by the constituent materials and the exact structure that is grown. The devices developed for this program operate between 850 nanometers and 1.06 microns.

When a moderate voltage (~15 volts) is placed across the shutter in reverse bias, the absorption feature changes, shifting to longer wavelengths and dropping in magnitude. Thus, the transmission of the device near this absorption feature changes dramatically. Figure 7 shows absorbance data for an InGaAs MQW modulator designed and grown at NRL for use in a modulating retroreflector system. The figure illustrates how the application of a moderate voltage shifts the transmittance. Hence, a signal can be encoded in an on-off-keying format onto the carrier interrogation beam.

The challenge presented by this application is that because the device is essentially a semiconductor, its speed is driven by the resistance-capacitance product in the time response. Capacitance is driven by area, but the area must be large to close a given link over useful ranges (typically on the order of a kilometer or more). NRL has successfully experimented with segmentation of the device, which both increases speed and increases yield while maintaining low-power draws.

Field Tests: Successful implementation of a modulating retroreflector link requires the integration of the device onto a platform as well as the ability to close a link while in flight. As a first step in developing an operational modulating retroreflector communications link, NRL has conducted two field tests to date, with follow-on tests planned. The aim of these tests was to demonstrate a short-range link to a platform that carried no active pointing system and indeed had relatively low platform stability. The tests were conducted in the fall of 1999 and in the winter

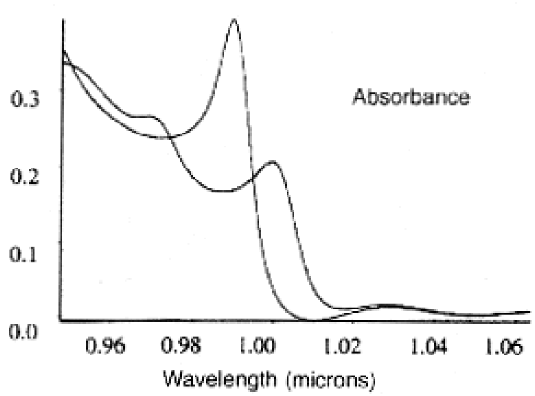

FIGURE 6
Absorbance vs frequency. In its quiescent state, the MQW shutter blocks the transmission of incident light. When a moderate voltage is applied, the absorbance shifts and light is transmitted through to the retroreflector.

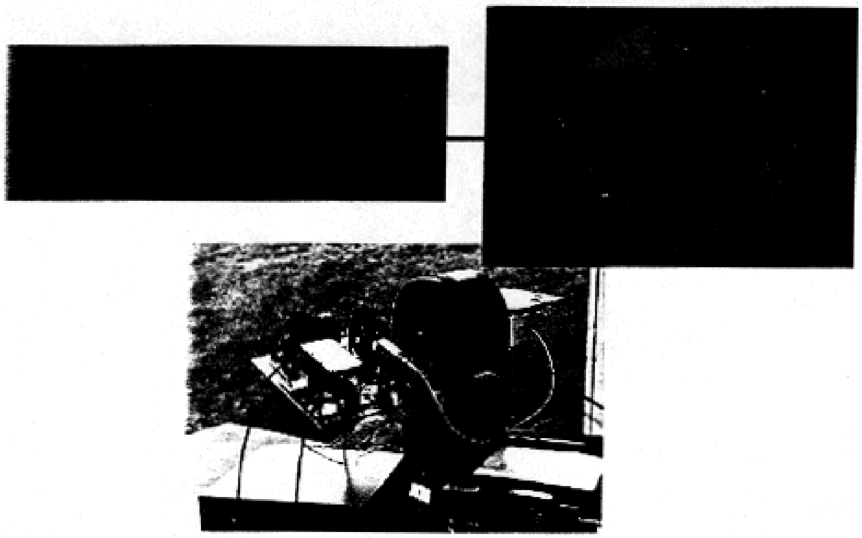

FIGURE 7
UAV, payload, and interrogator for NRL in-flight modulating retroreflector field test. The helicopter is about 1-1/2 meters long; the payload consists of a modulating retroreflector ringed by LEDs to aid in daytime acquisition and tracking; the interrogator consists of a laser diode and optics, with an avalanche photodiode configured in a Naysmith-mounted design on a small gimbal.

of 2000 at the NRL Chesapeake Bay Detachment facility in Maryland.

A 0.5-cm diameter InGaAs transmissive MQW modulating retroreflector was mounted on a small rotary-wing unmanned airborne vehicle (UAV), which was about 1-1/2 meters long. The retromodulator assembly was ringed by infrared LEDs that were used to provide a beacon for acquisition and tracking of the UAV. In future tests, these will be replaced with a ring of retromodulators to test self-acquisition and jitter-resistant tracking.

The modulating retroreflector was placed on the tail of the UAV pointing down. The UAV was flown at an altitude of about 35 meters and a range of 35 to 65 meters from the transmit/receive laser. The conditions for the test were somewhat adverse, with a light rain, fog, and low visibility. The second test was conducted with snow cover and in icy outdoor conditions. The UAV, payload, and interrogator are shown in Fig. 7.

Figure 8 shows a typical return from the field tests. In the two tests conducted, the modulation rates received in flight were 400 and 910 kilobits per second. However, the modulator and detector bandwidth and the returned signal level were sufficient to support a 2 Mbps link at low bit error rates, and in fact,

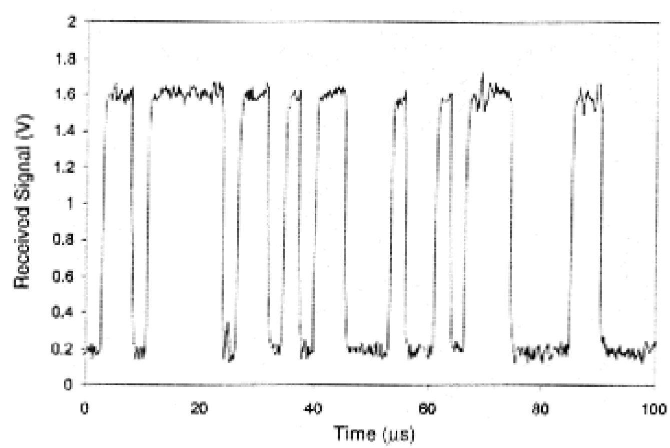

FIGURE 8
A sample of the return from data captured in flight using the NRL MQW retroreflector. As long as the link was maintained through accurate pointing and tracking, signal amplitudes were high enough to maintain a robust communications link.

captured uncompressed black and white video in pre-flight ground tests. The modulator consumed 40 mW of electrical power at this modulation rate.

Summary: We have shown that a multiple quantum well-based modulating retroreflector can enable a very small platform to passively close an optical data link. The use of such modulators can allow much higher bandwidth communications over longer ranges than is typical of such platforms using radio frequencies. In addition, the link is covert, very difficult to jam, and immune from the frequency congestion problems to which RF communications are susceptible.

[Sponsored by ONR]

References

[1] G.C. Gilbreath, S. Bowman, W. Rabinovich, C. Merk, and H.E. Senasak, "Modulating Retroreflector for Free Space Optical Data Transfer using Multiple Quantum Well Technology," U.S. patent no. 6154-299, granted November 28, 2000.

[2] G.C. Gilbreath, W.S. Rabinovich, T.J. Meehan, M.J. Vilcheck, R. Mahon, R. Burris, M. Ferraro, I. Sokolsky, J.A. Vasquez, C.S. Bovais, K. Cochrell, K.C. Goins, R. Barnehenn, D.S. Katzer, K. Ikossi-Anastasiou, and M.J. Montes, "Compact, Lightweight Payload for Covert Data Link using a Multiple Quantum Well Modulating Retroreflector on a Small Rotary-Wing Unmanned Airborne Vehicle," *SPIE Proc.* **4127**, July 2000, in press.

[3] D.S. Katzer, W.S. Rabinovich, K. Ikossi-Anastasiou, and G.C. Gilbreath, "Optimization of Buffer Layers for InGaAs/AlGaAs PIN Optical Modulators Grown on GaAs Substrates by Molecular Beam Epitaxy," *J. Vac. Sci. Technol.* **B 18**, 1609-1613 (2000).