Generation of 14 GHz radiation using a two frequency iodine laser

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A mode-locked and gain-switched photolytic iodine laser Zeeman tuned to operate simultaneously on the two strongest hyperfine transitions is shown to emit 1.315 $\mu$m radiation modulated at 13.9 GHz. The interaction of this laser radiation with suitable targets leads to the generation of microwave pulses that consist of only a few cycles at 13.9 GHz, making the system attractive for ultra-wide-band, short pulse radar applications. © 1998 American Institute of Physics.

A variety of laser systems have used optical heterodyning to modulate the laser radiation at microwave frequencies with the goal being to control microwave electronics through optical techniques, perform heterodyne spectroscopy, or investigate ultra-wide-band radar sources. The standard method is to beat two frequencies together and detect the difference frequency between the coherent beams with a semiconductor or fast photodetector. Typically, two different laser sources separated in frequency, but stabilized to each other are required. These microwave pulses have a well-defined, nonzero carrier frequency as opposed to radiation generated from a single (bandwidth-limited) optical pulse.

An alternative is to force a single laser to oscillate on two different frequencies simultaneously. An iodine laser is an attractive candidate for such experiments. First, iodine has well-separated hyperfine transitions, allowing for a beat note ranging from 0.78 GHz to greater than 20 GHz depending on which pair is selected. Second, small scale experiments, such as those described in this letter, can easily be scaled to extremely high powers with a chemical oxygen iodine laser, capable of producing 40 kW, with a variety of potential applications as an ultra-wide-band, laser driven, radar source.

The laser used for these experiments has been described in detail elsewhere, so only a brief description will be given here. A gas cell containing the active medium, CF$_3$I, was pumped by a 20 ns, 248 nm pulse from a KrF excimer laser. CF$_3$I dissociates into CF$_3$ and I$^*$ that lases at 1.315 $\mu$m. With an acousto-optic modulator and suitable intracavity apertures, the laser emitted a train of 10–20 pulses (depending on the pump energy and gas pressure) in a single transverse mode. For diagnostic reasons all experiments were performed with the second harmonic of the laser radiation which was generated either intracavity or extracavity yielding pulse energies of about 1 mJ. A magnetic field was applied to equalize the gain in the two strongest hyperfine transitions so as to force lasing on two transitions simultaneously, producing a beat note of about 14 GHz. The mode locker served two purposes: (i) the generation of laser pulses as short as 740 ps and (ii) the locking (optimum temporal overlap) of the two laser lines.

A schematic of the experimental setup to generate microwave radiation is shown in Fig. 1. We used a biased (1–2 kV) vacuum phototube and an unbiased GaAs wafer as targets. In both cases, a horn antenna picked up the microwave radiation.

The laser beam was expanded to fill the aperture of the phototube to minimize saturation effects. The signal picked up by the antenna was processed with one of two methods: mixing with a local oscillator in a heterodyne setup, and direct rectification in a crystal detector for microwaves with a subsequent low-pass filter. The heterodyne measurement had the advantage of supplying information about the microwave frequency, whereas the crystal detector gave a more accurate temporal profile of the microwave pulse envelope. Note that there is only a small range of possible local oscillator frequencies for the heterodyne detection as performed here. The upper limit is given by the bandwidth of the oscilloscope (1 GHz); the lower limit (~500 MHz) is determined by the duration of the mode-locked pulses.

The features of a typical mode-locked laser pulse train are shown in Fig. 2. The direct, electronic response of the phototube, as seen on an oscilloscope, is depicted in Fig. 2(a). Figure 2(b) shows the output of a mixer where the signal from the horn antenna was mixed with a local oscillator set to 14.6 GHz. A beat signal occurs at intervals corresponding to the optical pulse separation. The Fourier transform of this beat note is depicted in Fig. 2(c). The maximum

![FIG. 1. Experimental setup for detecting laser generated microwaves at 14 GHz.](image)
A typical signal from a crystal detector is shown in the top graph of Fig. 3. For comparison purposes, the laser pulse train, as detected by a fast photodiode for the same laser shot, is shown in the bottom graph. The strongest pulse in the microwave pulse train shows a width of $610 \pm 20$ ps. The shortest measured microwave pulse was $410 \pm 20$ ps, with the average pulse being $535 \pm 20$ ps. Since the oscilloscope had a bandwidth of 1 GHz the reported pulse duration is actually only an upper limit. A comparison of the individual pulse peaks in Fig. 3 reveals a weak saturation of the microwave signal at the larger pulse intensities.

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FIG. 4. Relative energy in the microwave signal as a function of (a) spot diameter of the laser beam on the GaAs wafer, and (b) angle between the propagation direction of laser beam and the emitted microwave.

In a second set of experiments we replaced the biased phototube by an unbiased GaAs wafer, approximately 3.5 cm square and 1.5 mm thick. The band edge of GaAs is at 1.43 eV; therefore, the frequency doubled laser radiation was strongly absorbed in a thin surface layer (~ 300 nm).

The heterodyne signal with the unbiased GaAs was approximately six times weaker than that from the biased phototube, and heterodyne detection was used for the microwave detection with a local oscillator at 14.6 GHz. The relative energy in the microwave signal was estimated by integrating the Fourier transform of the beat signal. This energy was measured as a function of the spot size and the polarization of the microwave.

The dependence of the polarization of the microwave signal as a function of the emission angle relative to the incident laser beam is shown in Fig. 4(b). The horn was aligned for a polarization both parallel and perpendicular to the polarization of the incident laser. The solid line shows the vertical polarization and the dashed line the horizontal polarization.

The fact that the emitted microwave signal does not increase with the incident laser intensity suggests that a non-linear polarization does not contribute significantly. On the other hand the fact that the emission reaches a maximum when the excited antenna has a length of approximately half the microwave wavelength is expected from a linear antenna. The emission mechanism is likely to have similarities with THz wave emission observed from various unbiased targets when illuminated with femtosecond light pulses. This phenomenon was explained by the acceleration of excited carriers in the static built-in field at the depletion layer near the semiconductor surface. Unlike with fs illumination, in our case, the microwaves have a well-defined carrier frequency in the GHz range. The measurement results obviously do not describe a simple dipole radiation pattern. The latter would require a zero microwave signal for the perpendicular polarization. This is not surprising given the tensor character of the polarizability.

In conclusion, we have used Zeeman tuning to realize simultaneous lasing on two hyperfine transitions of a mode-locked photolytic iodine laser. Freely propagating microwave pulses were generated from biased and unbiased targets with a carrier frequency of 14 GHz and durations of a few hundred ps making this technique attractive for ultra-wideband radar applications.

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