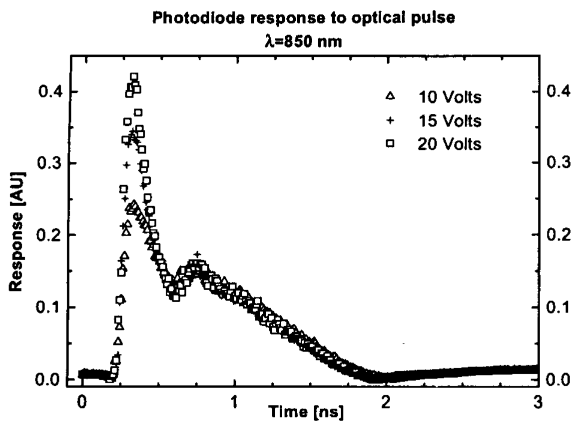

CMD5 Fig. 3. Response of deep trench-based silicon photodetectors for three bias levels.

depletion, consistent with the substrate doping of 10^{15} to 10^{16} cm^{-3}. The tail is suspected to arise from absorption below the trenches. This effect can be eliminated with smaller spacings and deeper trenches for use at 850 nm.

We have successfully designed and fabricated a new deep-trench silicon photodetector compatible with silicon integration. The trench-based design decouples absorption depth from carrier collection. We have fabricated devices with dark currents as low as nA's with optical responsivities between 0.32 and 0.65 A/W, approaching ideality.

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CMD6 **9:15 am**

Bias Dependent Nonlinear Responses of LTG-GaAs Based p-i-n/n-i-n Traveling-Wave Photodetectors Under Long Wavelength Excitation

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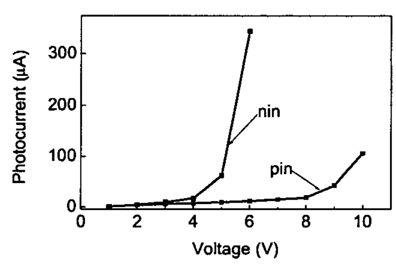
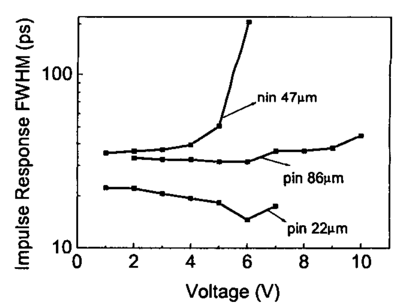
The application of LTG-GaAs based photodetectors at communication wavelength (1.3 ~ 1.55 um) attracts lots of attentions[1,2] due to its high speed high saturation power performances as well as its capability of integration with mature GaAs-based high speed IC technology. Recently, Chiu *et al* had demonstrated the high-speed/high-sensitivity LTG-GaAs based n-i-n/p-i-n traveling-wave photodetectors (TWPDs) in the long wavelength (1.3 – 1.55 um) regime with high saturation power performance.[2] In this paper, we report the observation of interesting new single-carrier-type photocurrent behaviors in these novel photodetectors under long wavelength excitation. Under high bias and long wavelength (~1300 nm) excitation, strong nonlinear responses both in transit state (impulse response) and steady state (D.C. photocurrent) are observed. These interesting nonlinear behaviors open a new way in the application of photomixing devices.

The device structures (n-i-n/p-i-n TWPD) performed in this study are similar to the structure published in.[2] The optical source for both D.C. and impulse photocurrent response measurements is a Cr:forsterite laser with a center wavelength at 1240 nm. Figure 1 shows typical D.C. photocurrent responses with a constant optical power (10 mW) excitation measured for a 47-μm-length n-i-n and an 86-μm-length p-i-n TWPDs. The active area for both devices consists of a 200 nm thick LTG-GaAs with a waveguide width of 2 μm. We can clearly see a significant photocurrent "turn on" behavior in both devices under high bias. These "turn on" voltages are about 4 V and 7 V for n-i-n and p-i-n TWPDs respectively. The slow increase of photocurrent with increased applied voltage under lower bias is attributed to the increase electron drift velocity. The drastic photocurrent increase with increased applied bias under high bias situation is attributed to the increase of electron trapping under high electric field (voltage) in LTG-GaAs photo-absorption layer.[3] Compared with the p-i-n TWPD device, the n-i-n TWPD device has a lower "turn on" voltage with a higher turn on current (or quantum efficiency) due to the fact that the electric field located in LTG-GaAs layer with a fixed external bias is much stronger in the n-i-n case[2] thus with a much significant trapping time increase.

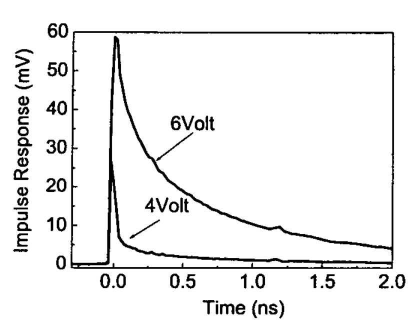


CMD6 Fig. 1. D.C. photocurrent v.s. bias voltage for n-i-n and p-i-n TWPDs under 10 mW 1240 nm optical power excitation. The device lengths for the measured n-i-n and p-i-n TWPDs are 47-μm and 86-μm respectively. The maximum device voltage is limited by device breakdown.

These devices' corresponding transient responses were measured with a 50 GHz sampling scope under 100 fs 1240 nm pulse excitation. Figure 2 plots the devices' electrical response FWHM as a function of applied bias also under 10 mW average power excitation. The short absorption length (22 μm) p-i-n TWPD has a much faster response (less than 20 ps) due to wider velocity-mismatch and microwave loss bandwidth due to short device length.[4] Both p-i-n TWPD exhibits a decrease of impulse response FWHM with increased voltage in low bias situation (voltage less than 6 ~ 7V), and this trend is more significant in the short device. This effect is attributed to the increased electron drift velocity with increased bias in the low bias regime. For long device length TWPDs this effect is not so obvious due to the fact that device bandwidth is dominated by microwave related effects.[4] However under high bias (higher than 6 V), response FWHM in all traces broadens. This result is attributed to the increase of electron



CMD6 Fig. 2. FWHM of device impulse response v.s. bias voltage under 10 mW 1240 nm optical power excitation. The maximum device voltage is limited by device breakdown.



CMD6 Fig. 3. Impulse response of a 47-μm-long n-i-n TWPD device under 6 V and 4 V bias.

trapping time in high electric field and is consistent with the result in DC current measurements. This effect is especially pronounced in the n-i-n TWPD due to higher electric field inside the active region. For the n-i-n trace, we can see that there is a drastic increase of response FWHM from 39 ps to 206 ps with a bias increase from 4 V to 6 V. The measured transient electrical response traces for the n-i-n TWPD with 4 V and 6 V bias are shown in Figure 3. This long impulse response time and the high photocurrent under 6 V bias indicate that under the high bias condition the n-i-n structure behaves like a typical lifetime-limited bandwidth photoconductor device, and electrons are "looping"in the external circuit to support charge neutrality until they are recombined or trapped.

With such a large bias-dependent photocurrent behavior in n-i-n/p-i-n TWPDs under long-wavelength excitation, this nonlinear behavior can used for photo-mixing in microwave photonic communication systems. More details will be discussed in the presentation including the effect of space charge effects in single-carrier-type devices.

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CMD7 9:30 am

Integrated Optical Phase Modulator using an Hybrid Structure of Glass Waveguides and Electro-Optic Polymers

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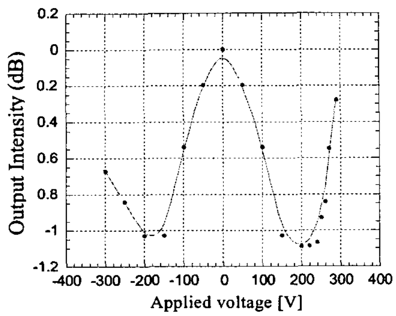
The recent expanded use of information services increases the requirement of high speed and bandwidth of optical telecommunication systems. That surge in demand for photonic components to stack, control and process a great amount of information. In telecommunication, the organic materials offer new possibilities for the development of electro-optic (EO) devices with good performances.[1] The interest stems from their excellent electro-optic coefficient and large bandwidth, as well as their easy processability and low cost. In addition, they provide the possibility to integrate easily witho ther materials like glass substrates. The hybridation of glass ion exchange waveguides technology with that of the EO polymers permits the integration of passive and active functions in a multifunctionald evice. This technique offers a different approach in which complex passive functions, with low propagation losses, produced by the ion exchange technology can be integrated with large bandwidth electro-optic active functions in the same substrate.

We have fabricated a modulator with a vertically stacked structure, which consists of a single mode ion exchange waveguide recovered with a low refractive index poled EO polymer ($n \approx 1.5$; $r_{33} = 12$pm/V) sandwiched between a lower transparent electrode (ITO indium tin oxide) and an upper aluminium electrode. To avoid induced losses of the metallic layer, a buffer cladding is deposited between the upper electrode and the polymer. A similar structure have already proposed for a TE pass polarizer.[2]

A DC voltage signal is applied to induce a phase shift of the TM state respect to the TE state of the optical signal propagating in thew aveguide. The modulation response was measured by placing the device in an interferometric set up to convert phase modulation into amplitude modulation (figure). The half wave voltage measured for 0.3 cm modulation length was $V\pi = 200$ V.

A reduction of the driving voltage is expected with a longer electrode length and a polymer with a largerr ^{33}value. The low modulation depth derives from a difference in the propagation losses between the TE and TM modes.



CMD7 Fig. 1.

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CME 8:00 am–9:45 am
Room: 327/328

Ultrafast X-rays

Martin Richardson, *Univ. of Central Florida, USA, Presider*

CME1 8:00 am

X-ray and extreme ultraviolet emission induced by variable laser pulse-width irradiation of Ar and Kr clusters and droplets

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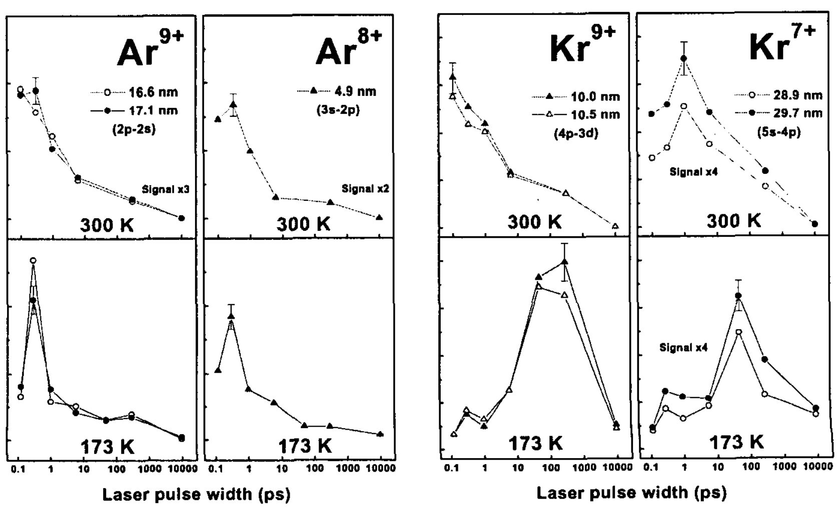
In recent years, the interaction of high intensity laser pulses with atomic clusters has become a very active area of research. The clusters are van der Waals bonded assemblies of $\sim 10^2$–10^7 atoms which form during rapid cooling during flow through a supersonic nozzle. Such short pulse heated clusters eject keV electrons and highly charged ions, generate strong emissions of keV X-rays, and exhibit very high laser energy absorption.[1] Laser heating of clusters is dominated by collisional absorption, a process more typical of solid targets. This enhances the energy absorbed compared to unclustered subcritical density gases and makes laser irradiated cluster gas



CME1 Fig. 1. Time integrated EUV emission from selected L-shell argon and M-shell krypton ion lines vs. laser pulse width.