Generation of ultrashort electrical pulses in semiconductor waveguides

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Ultrashort electrical pulses

Continuous interest in generation and propagation of ultrashort electrical pulses.

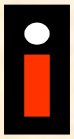
- Material characterization.
- Transmission line modelling.
- Semiconductor device characterisation.

Optically generated ultrashort electrical pulses:

- Photoconductive switch.
- Optical rectification. (can be done in a passive device)

Propagation:

- Transmission lines.



Optical Rectification

Optical rectification (OR) is a second order non-linear effect, and usually refers to the generation of a dc electric polarisation by an intense optical beam propagating in a non-linear medium.

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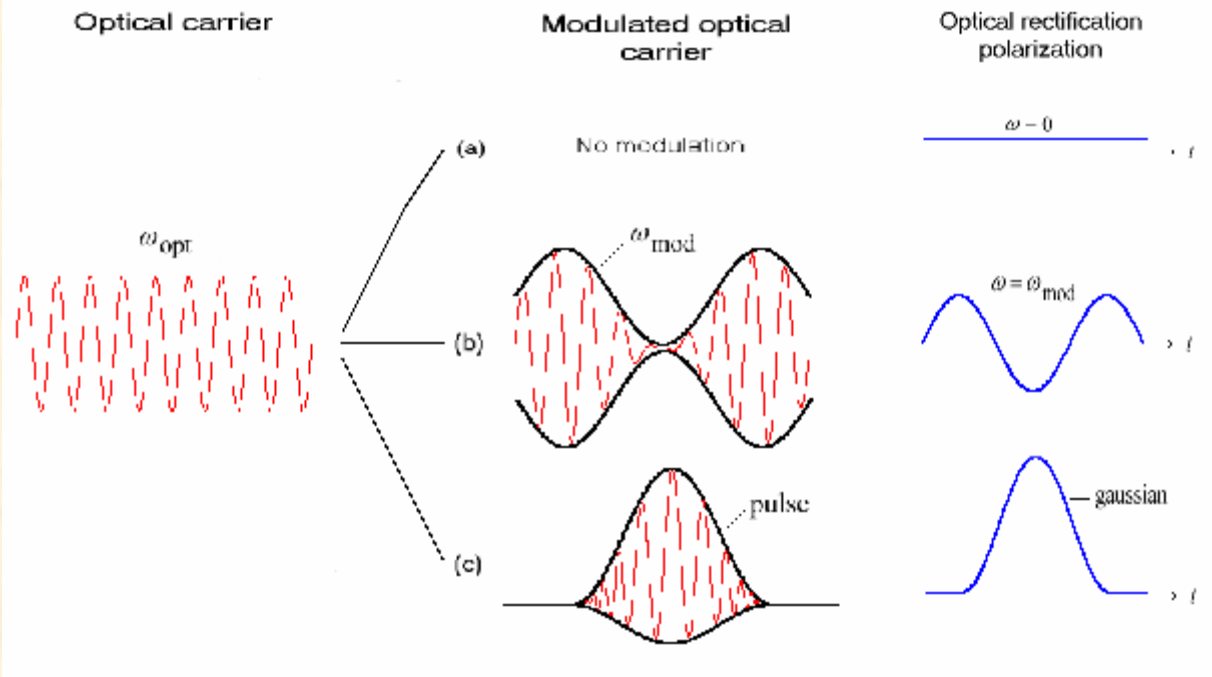
$$Pa\,E^2 \longrightarrow Pa\cos^2 wt = 1/2\left(1+\cos 2wt\right)$$

OR — SHG

The optical rectification polarisation can be modulated by modulating the optical carrier.



WG Optical Rectification

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ORE as the mechanism for generation of ultrashort electrical pulses in metal electrodes has been demonstrated before in non-linear crystals[1] and semi-insulated III-V semiconductor substrates[2].

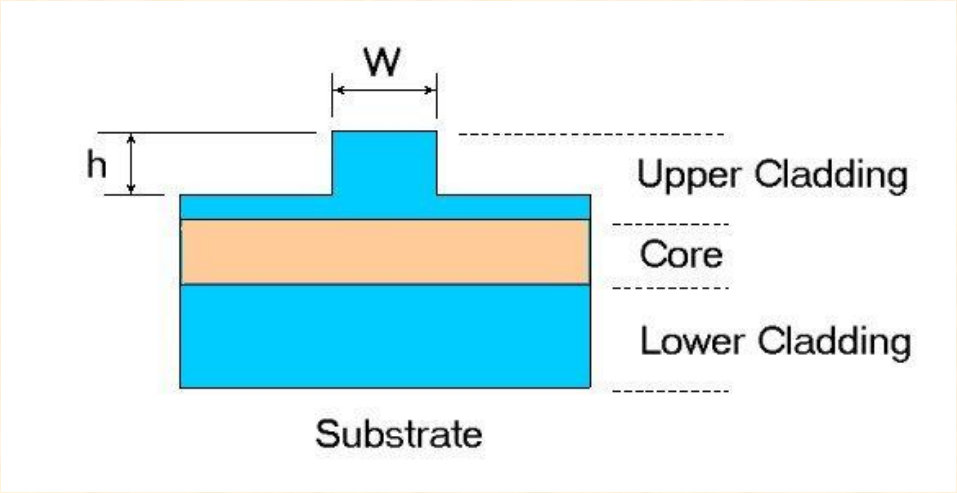
The presence of OR in semiconductor waveguides has been suggested before[3], but the signal has not been discriminated experimentally from unwanted free carrier signals.

The importance of OR in semiconductor waveguides is its compatibility with integrated optics.

The GaAs/AlGaAs system is a good non-linear material due to the large nonlinear coefficient of GaAs at communication wavelengths
($(c^2 = 238$ pm/V at $\lambda = 1.548$ μm)

[1] M. Bass, et al. Phys. Rev. Lett. **9**, 446 (1962)
[2] S. Graf, et al. Appl. Phys. Lett. **76**, 2647 (2000)
[3] M. Cada, IEEE J. Quantum Electron. **31**, 269 (1995)

Optical Waveguide



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Layer	Material	Doping	Thickness (μm)	Comments
Upper Cladding	AlGaAs 24%	i	1.0	
Core	AlGaAs 18%	i	1.5	Composition to reduce TPA at λ = 1550 nm.
Lower Cladding	AlGaAs 24%	i	4.0	
Substrate	SI-GaAs		400	

Single-mode structure: W = 5 μm
h = 0.85 μm

Prop. loss = 1.8 dB/cm

n_{opt} = 3.45

Coplanar Transmission Line

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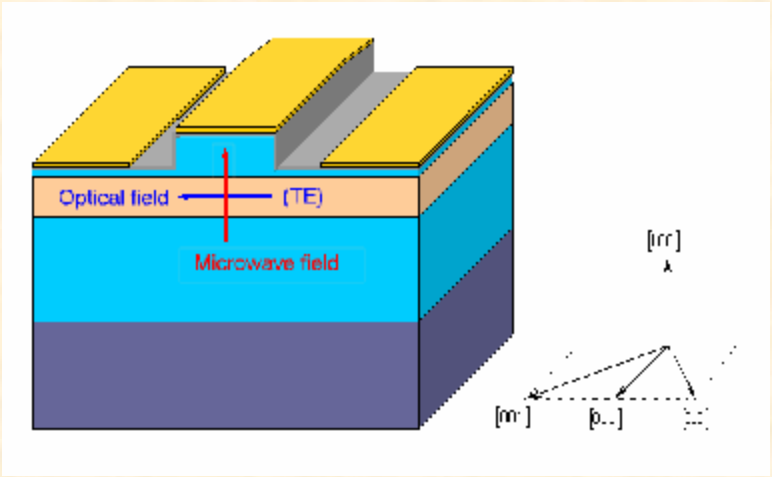
A CPW line will collect and propagate the electrical pulse generated by the pulsed optical beam travelling underneath.



Central conductor on top of the ridge.

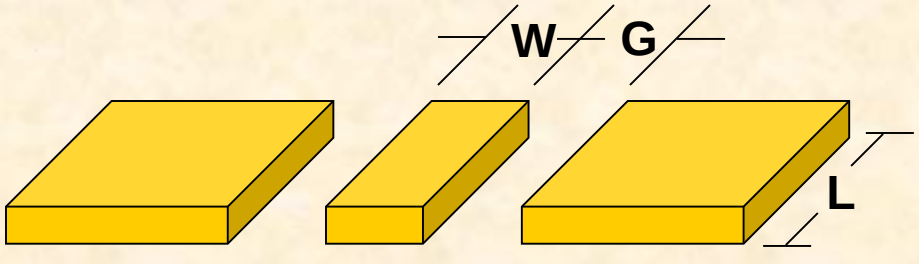
Ground electrodes in close proximity to maximise the overlap between the optical and microwave mode.

Small CPW line geometry leads to high conductor losses.

If the optical and the electrical signal travel at the same velocity, then we obtain a travelling-wave optical rectification device.

The CPW line can be engineering to velocity-match the optical wave.

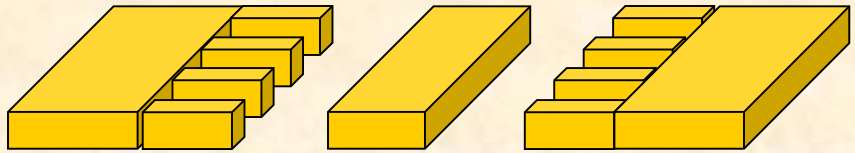
Velocity Matching



"PLAIN ELECTRODES"

$n_{mw} \approx 2.64$

- Electrical pulse subject to dispersion and attenuation.
- Conversion efficiency of 8.8×10^{-7}‡.



SLOW-WAVE ELECTRODES

$n_{mw} \approx 2.64 - 3.64$

- Loaded ground electrodes slow down the electrical signal.
- Electrical pulse travelling attached to the optical pulse.
- Conversion efficiency of 1%‡.

The refractive index is the parameter used to compare the optical and the electrical signal. Therefore $n_{opt} = n_{mw}$ is the condition for a velocity-matched structure.

‡ U. Peshel, et al. Phys. Rev. A, **60**, 4918 (1999).

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Modelling

Microwave office provide a 2D electromagnetic solution for transmission lines of any geometry.

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Microwave office → S parameters → ABCD parameters

$$g = \frac{1}{L}\left[\ln\left(\left(\frac{A+D}{2}\right) \pm \sqrt{\left(\frac{A+D}{2}\right)^2 - 1}\right)\right]$$

$$g = a + jb$$

$$v_{ph} = \frac{2p\,f}{b}$$

$$n_{mw} = \frac{c}{v_{ph}}$$

Simulations

Device	p	d	W	G	L
025	4	16	4	3	100
029	8	16			
033	16	16			
073	4	30			
077	8	30			
081	16	30			

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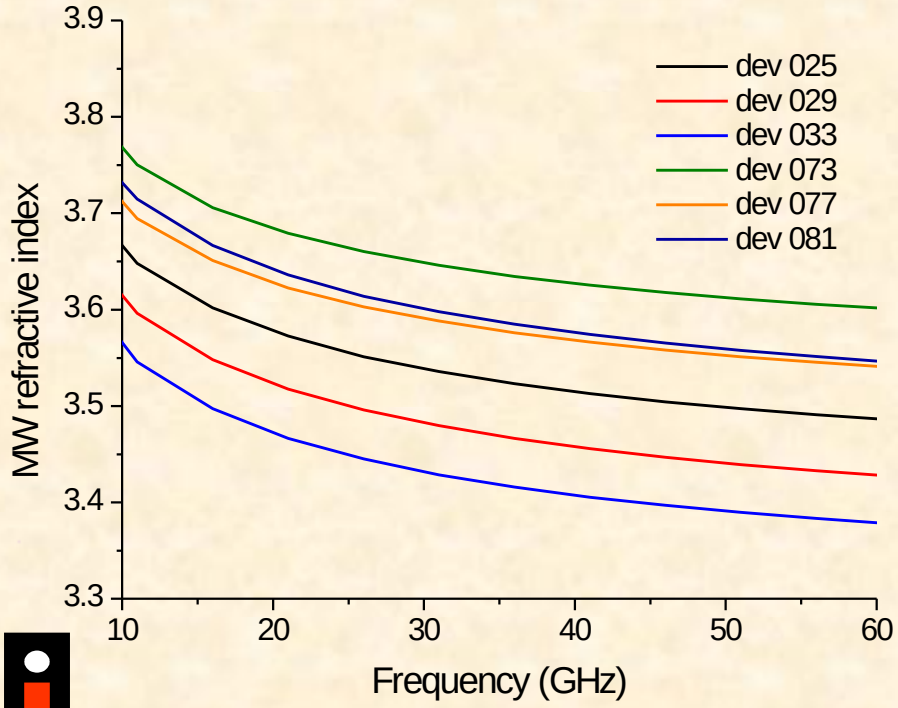
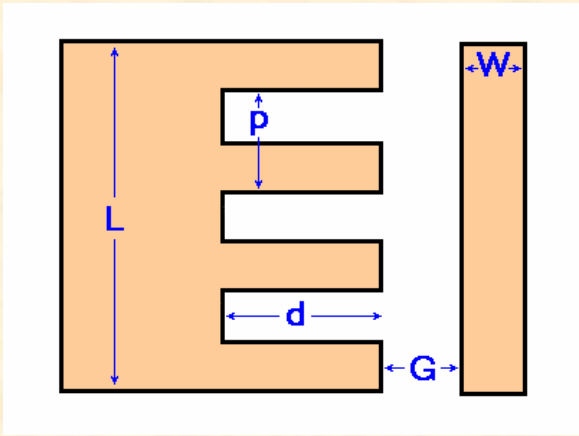
All dimensions In μm.





At 40GHz, dev 029 is optimum:

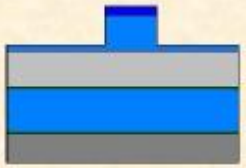
$n_{mw} = 3.45$

Fabrication

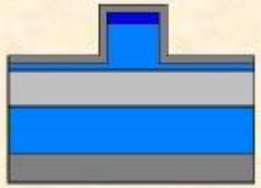
The devices were fabricated using direct writing E-Beam techniques.

Spin PMMA resist.

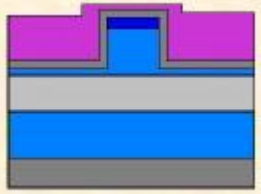
Direct E-Beam writing and develop.



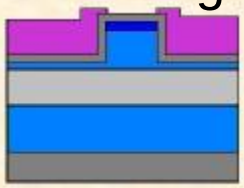
Dry etching of the ridge waveguide 0.85 μm depth.



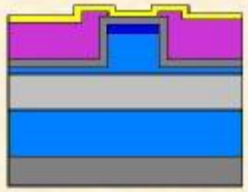
SiO_2 deposition 200 nm.



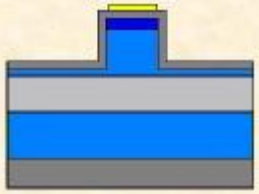
Spin bi-layer PMMA resist.



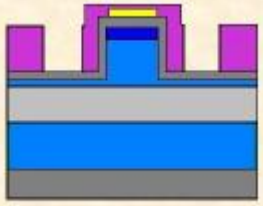
Window opening on top of the ridge.



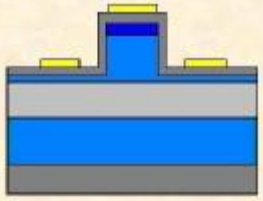
NiCr/Au evaporation 50 nm / 400 nm.



Lift-off.



Spin PMMA resist and window opening.



NiCr/Au evaporation and lift-off.

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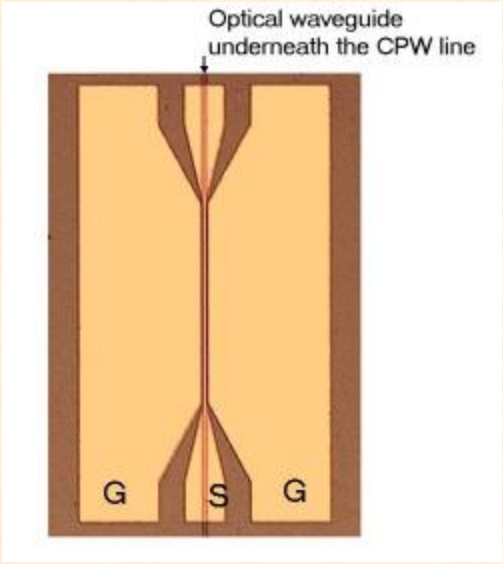
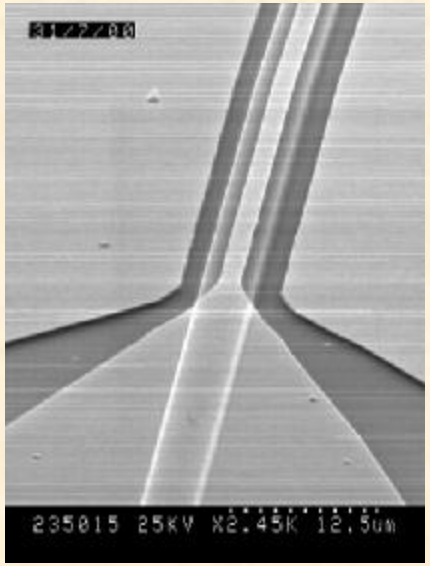
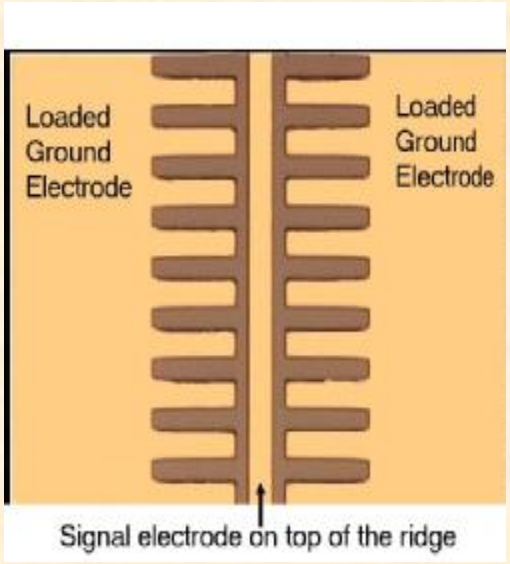
ORE devices







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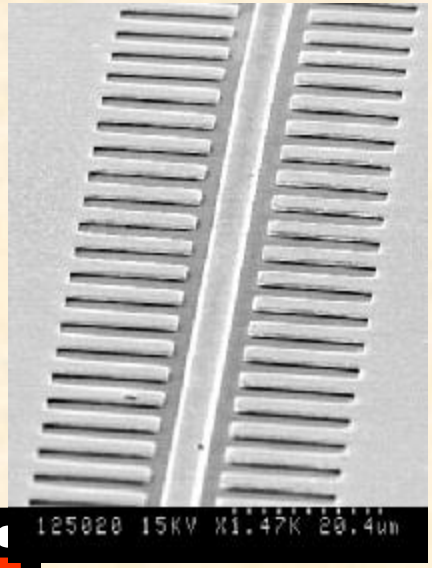

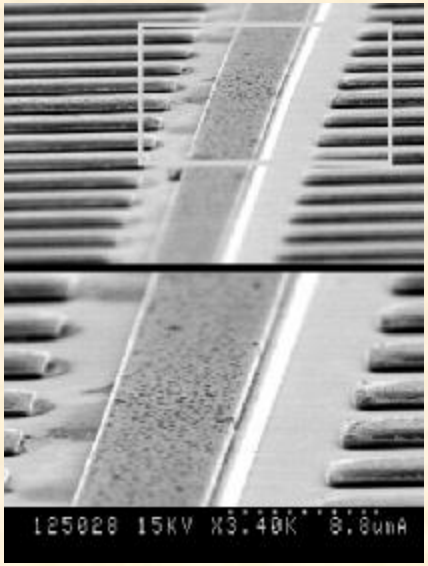

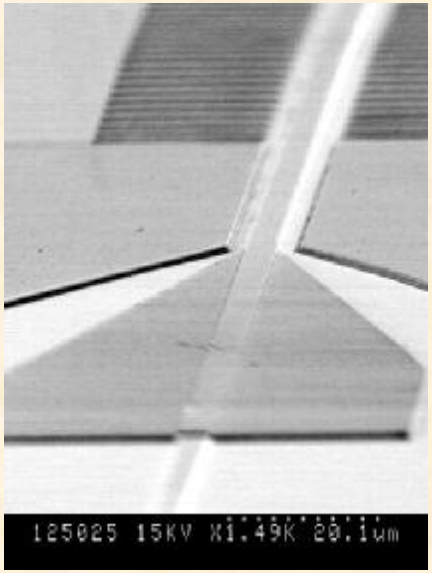

Electrical characterization

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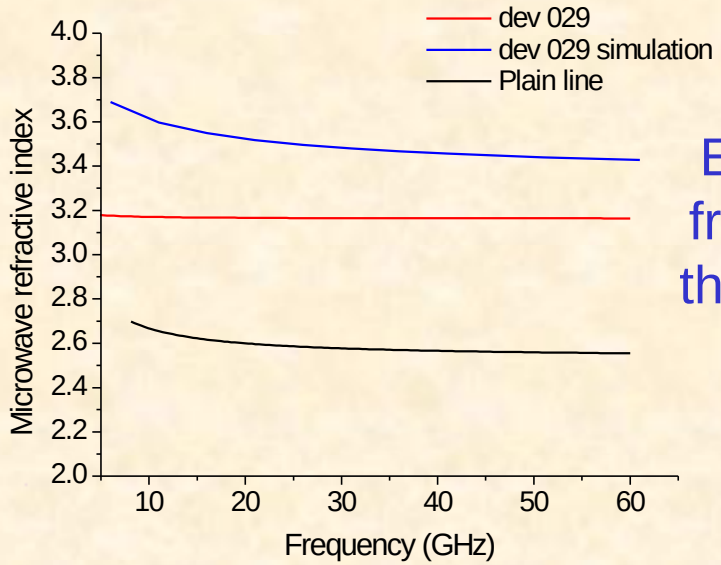
The frequency range is 10 GHz to 60 GHz.

Thru-Reflect-Line (TRL) calibration was used to measure the lines.

The calibration planes were set to the end of the tapers in order to obtain the parameters of the line itself.



Even when the refractive index was increased from 2.6 to 3.2, there is a discrepancy between the modelled and the measured result. This can be due to the accuracy of our reference impedance used in the calibration.

ORE Experiments

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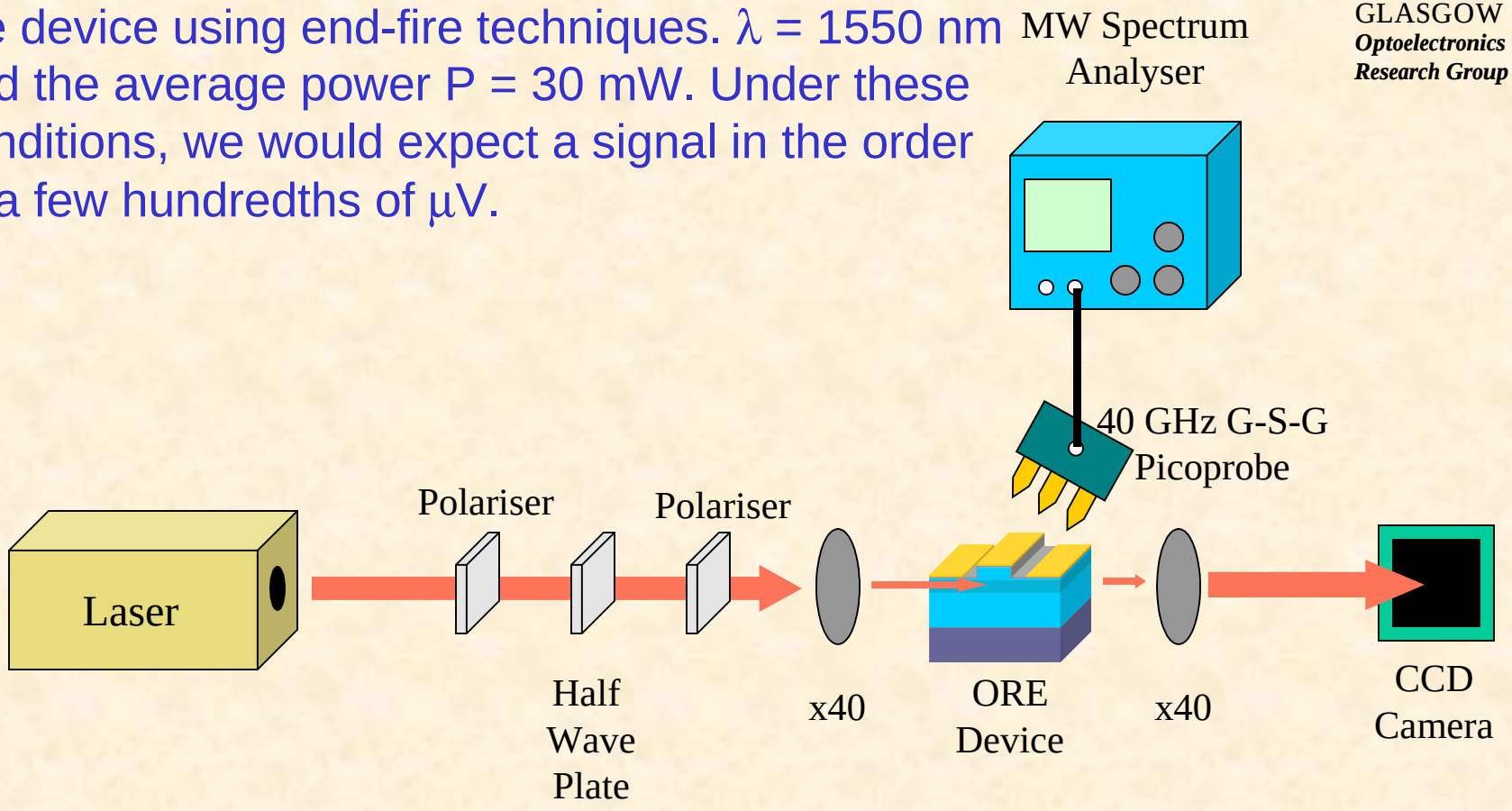
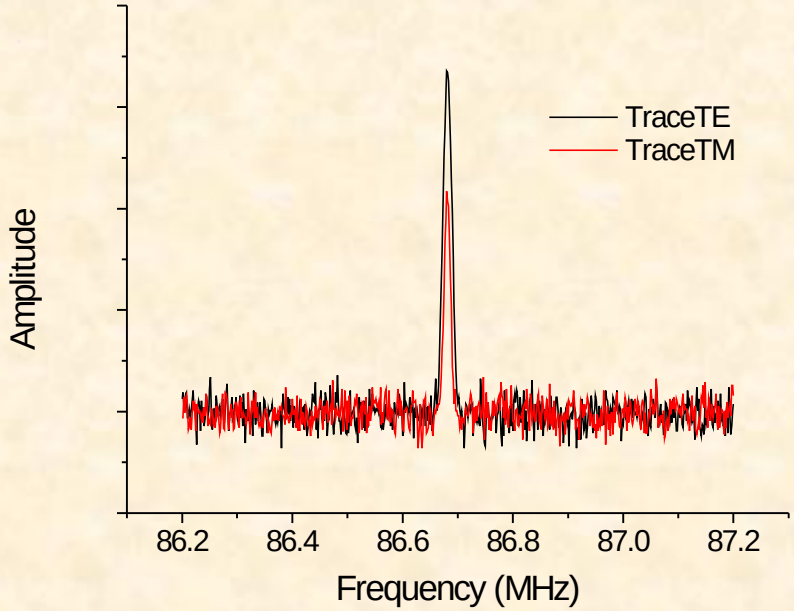
Light from a 300 fs pulsed OPO was coupled into the device using end-fire techniques. λ = 1550 nm and the average power P = 30 mW. Under these conditions, we would expect a signal in the order of a few hundredths of μV.



ORE Experiments



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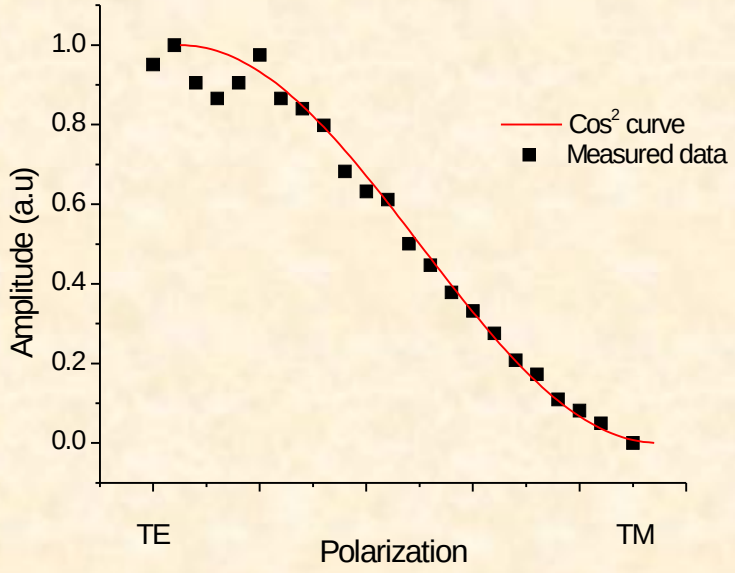
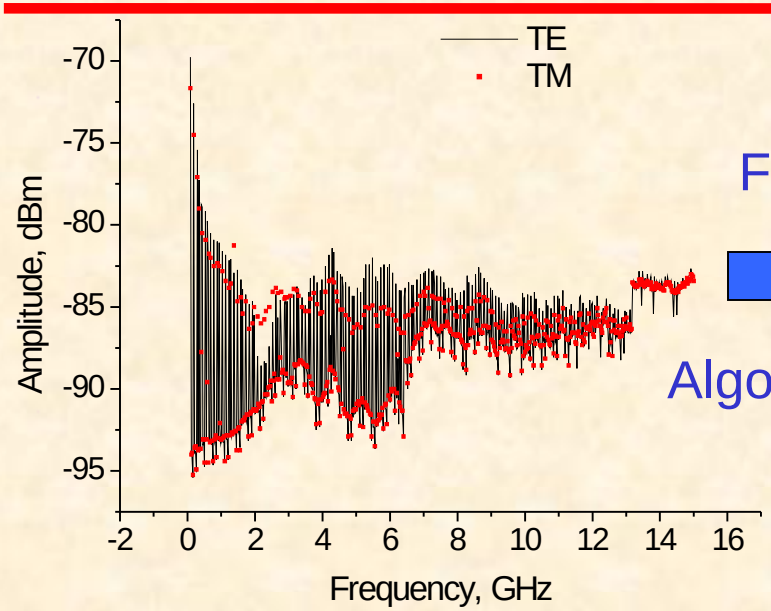
The signals detected in the device are very week. This suggest a very low conversion efficiency maybe because the device is not perfectly velocity-matched.

The polarization dependence of the signal follows a Cos^2 behaviour as expected from the ORE.

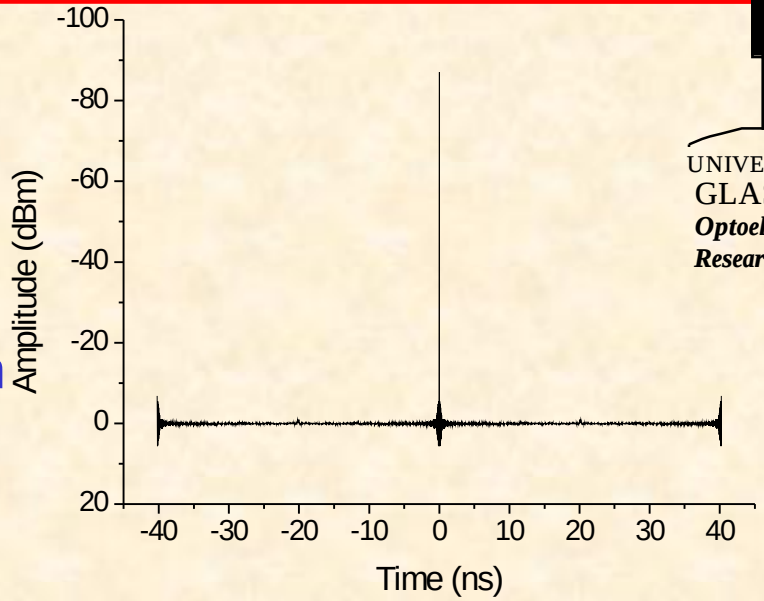


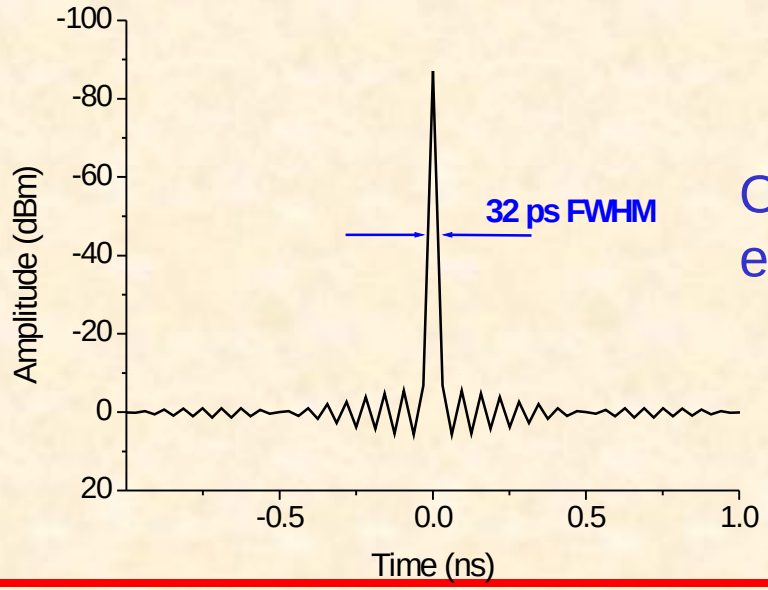
ORE Experiments



FFT

Algorithm





ORE ultrashort electrical pulse

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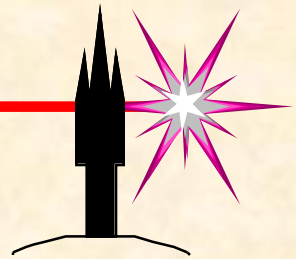
Conclusions



- A novel optical rectification device has been proposed.
- The optical part of the device can be designed separately from the electrical part and vice versa.
- Velocity-match is achieved using slow wave electrodes.
- A reasonable straight forward fabrication process was proposed.
- The Optical Rectification signal is very week suggesting poor velocity-matching.
- Pulses of 32 ps FWHM have been obtained using an optical excitation of 300 fs.