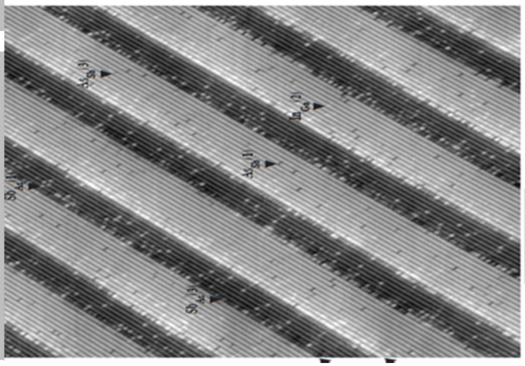
SAND2014-20697PE

Photos placed in horizontal position with even amount of white space between photos and header



Improved Carrier Lifetime Measurement Sensitivity in InAs/InAsSb Superlattices

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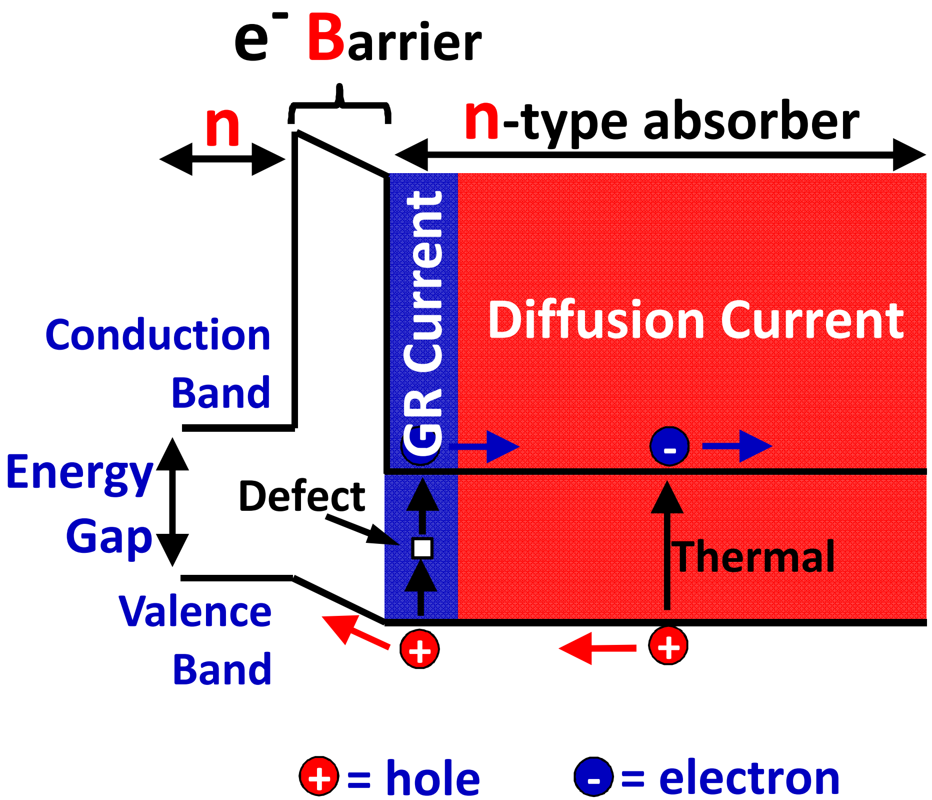
outline

- Time-resolved Photoluminescence
- DC Modulated Photoluminescence
- Time-resolved Photoconductivity decay Microwave
- DC Modulated Photoconductivity

Dark Current

nBn photodetector



Diffusion Current

$$J_{Diff} = q\frac{n_i^2 L_{abs}}{N_d \tau_{MC}}$$

- τ_{MC} = minority carrier lifetime
- n_i = intrinsic carrier density
- N_d = doping level
- L_{abs} = absorber width

GR Current

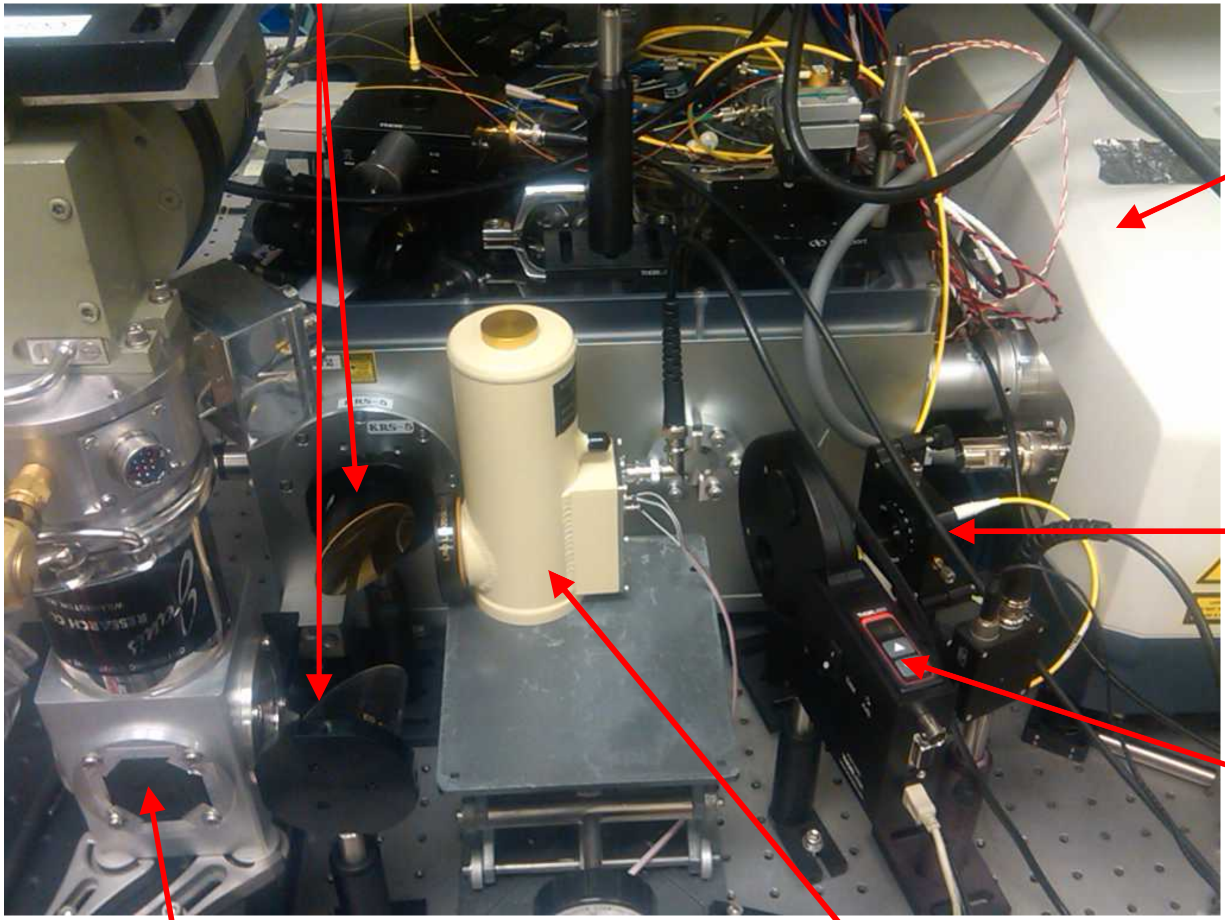
$$J_{GR} = q\frac{n_i L_{depl}}{\tau_{po} + \tau_{no}}$$

- τ_{no} = majority carrier SRH lifetime
- τ_{po} = minority carrier SRH lifetime
- L_{depl} = depletion layer width
- q = electronic charge

Goal is to *minimize* dark current generation and *maximize* photocurrent generation/collection

Time-Resolved PL

Collection and Focusing Optics



FTIR for spectral analysis

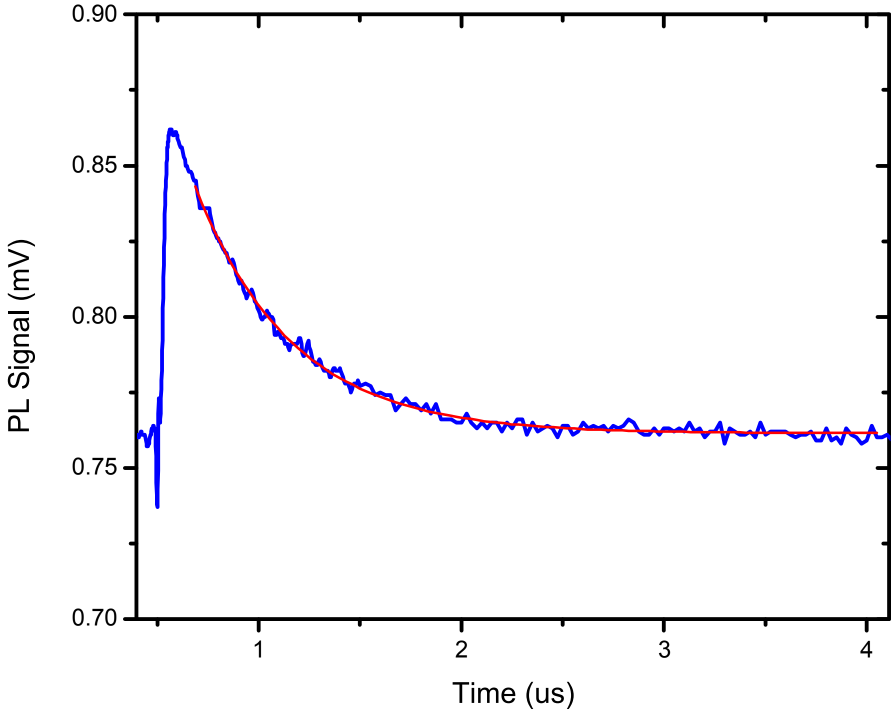
Pulsed Laser

Filter wheel

Fast detector

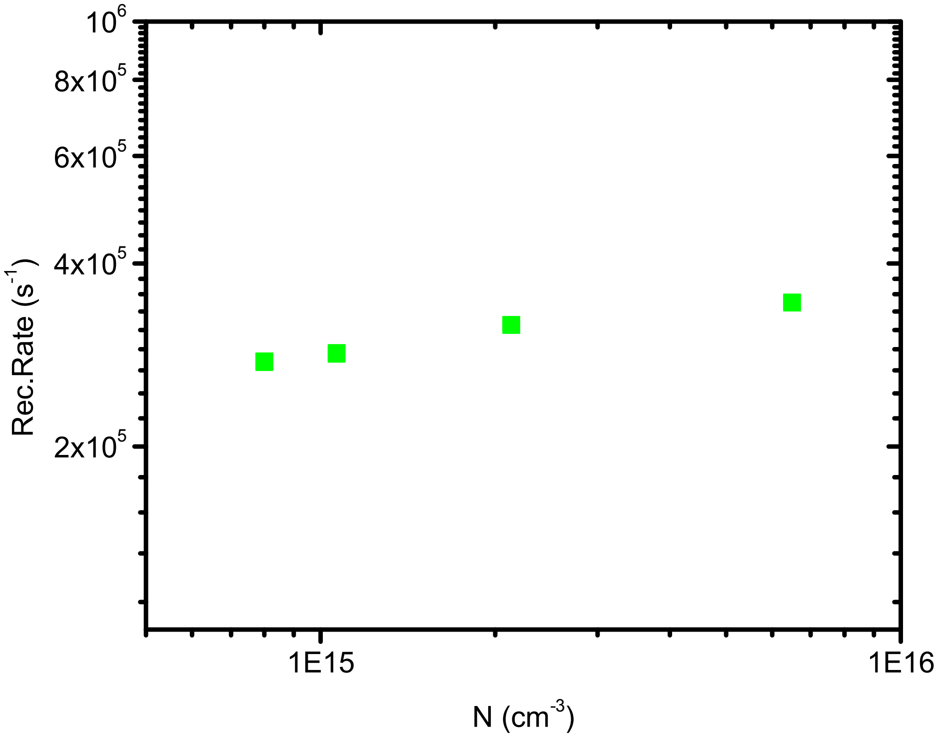
Sample in cryostat

Time-resolved Photoluminescence



Sample Description

- $InAs/InAs_{0.67}Sb_{0.33}$ T2SL
- 5.2um bandgap @100K
- Unintentionally doped (N_D=1e15cm^{-3})



Benefits

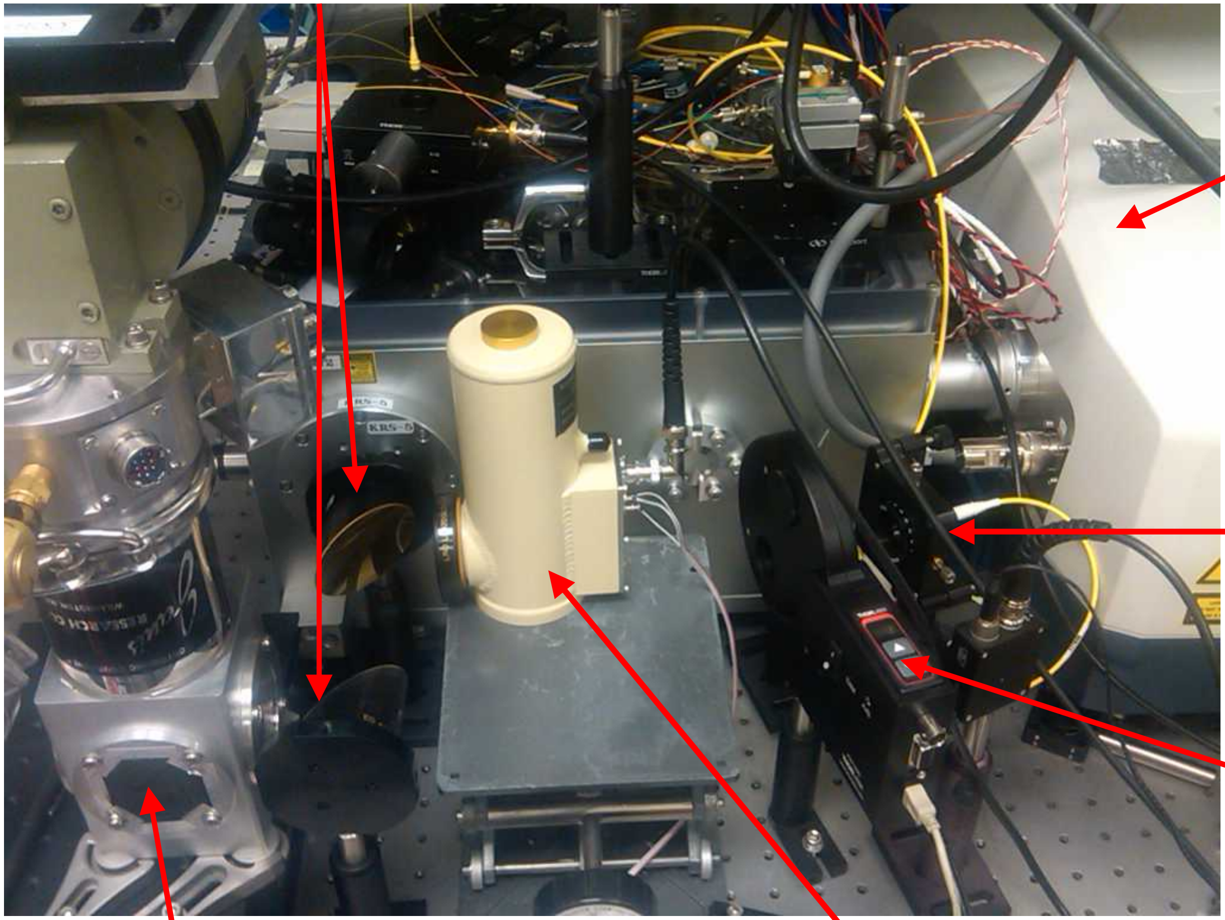
- Relatively Low cost
- Straightforward alignment

Cons

- Carrier lifetime has squared dependence on PL lifetime

DC Modulated PL

Collection and Focusing Optics



FTIR for spectral analysis

Telecom Laser

Filter wheel

Fast detector

Sample in cryostat

DC Modulated PL

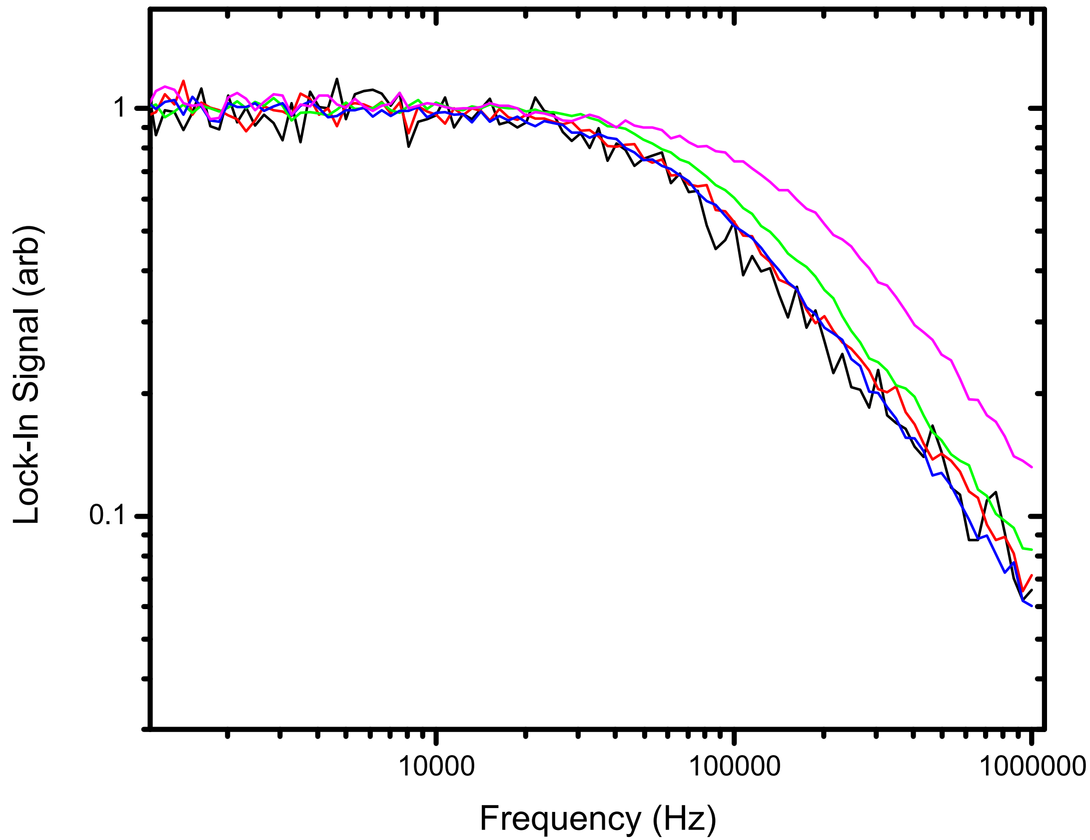
- Sinusoidal excitation

$$G(t) = G_0 + G_1\cos(\omega t)$$

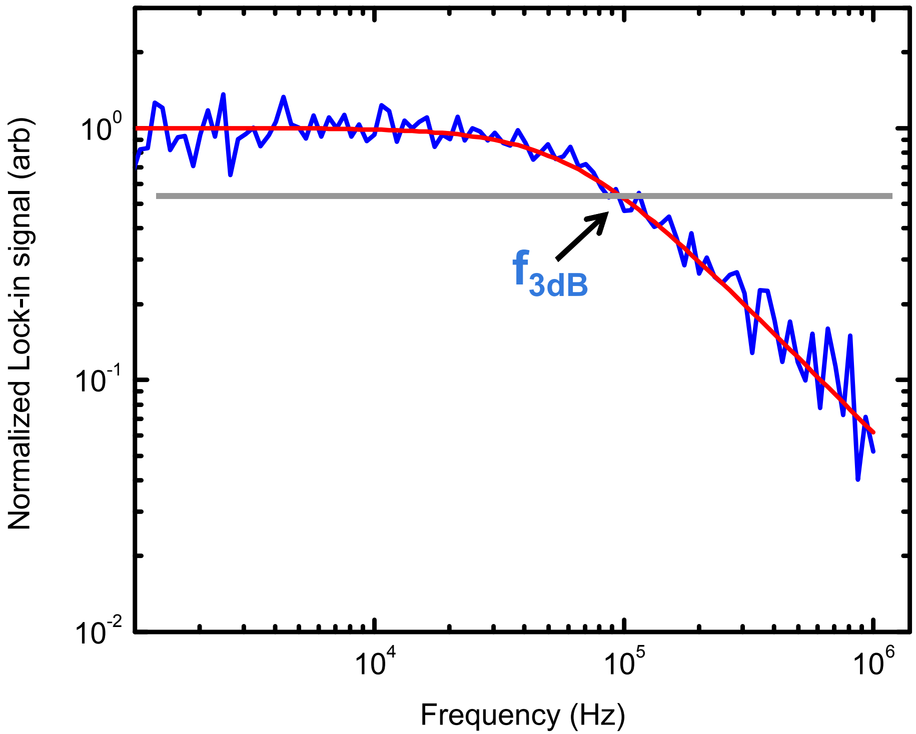
- Photoluminescence goes as

$$I_{PL}(\omega) \propto \frac{G_1\tau}{\sqrt{1+(\omega\tau)^2}}$$

$$\tau = 1/2\pi f_{3dB}$$



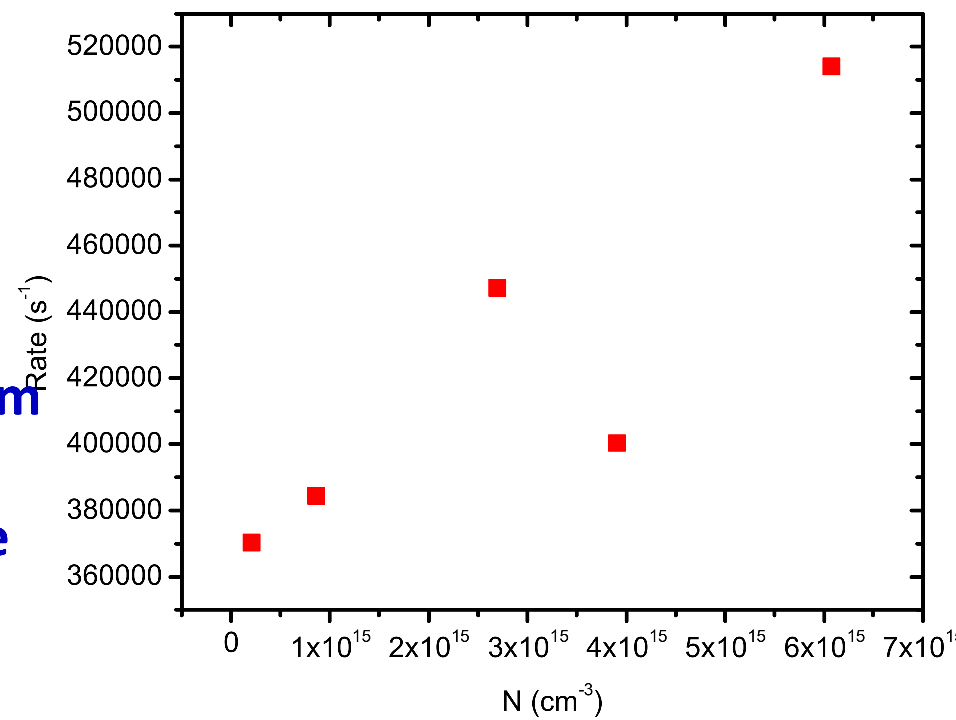
DC Modulated PL



$$\tau = 1/2\pi f_{3dB}$$

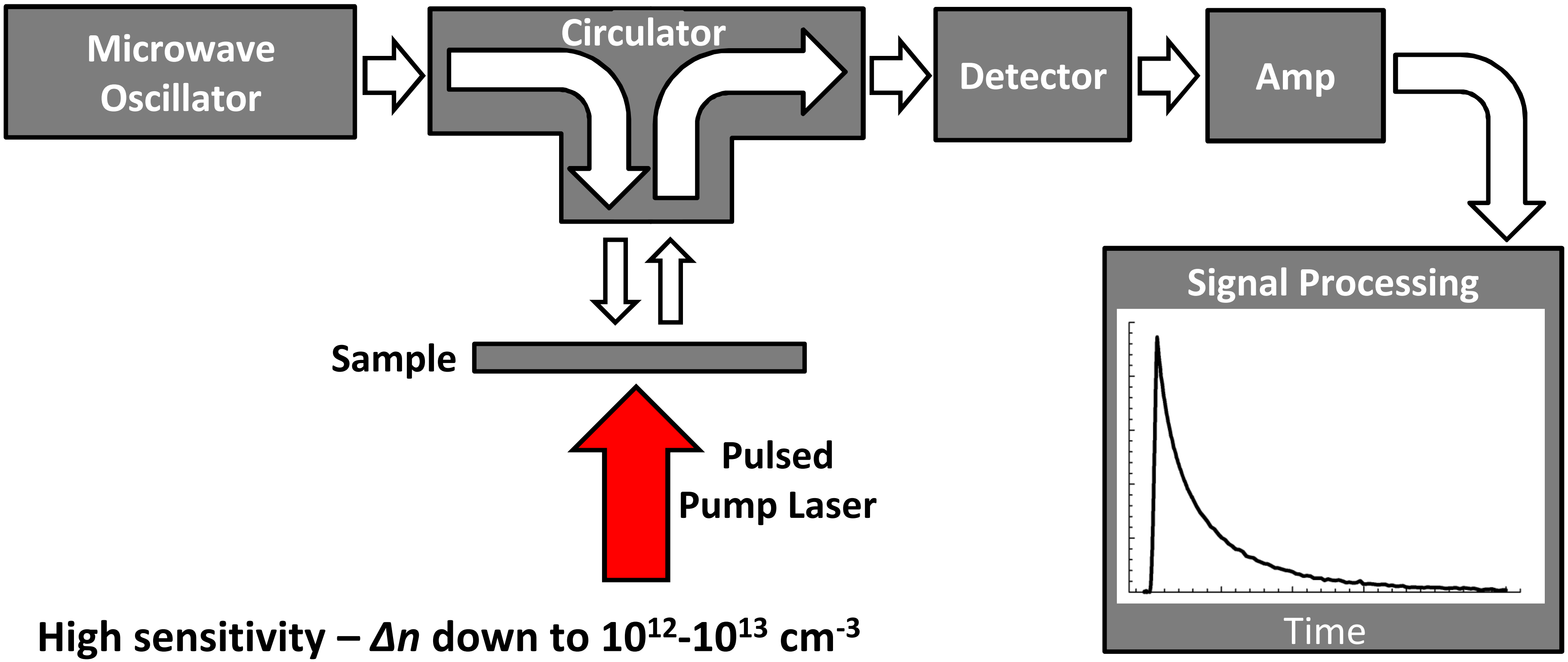
$$\frac{1}{\tau} = A + BN + CN^2$$

Inverse Carrier Lifetime vs. DC Carrier Density



- **Excess carriers injected using 1625 nm pump**
- **Signal roll off measured from change in PL from sample**

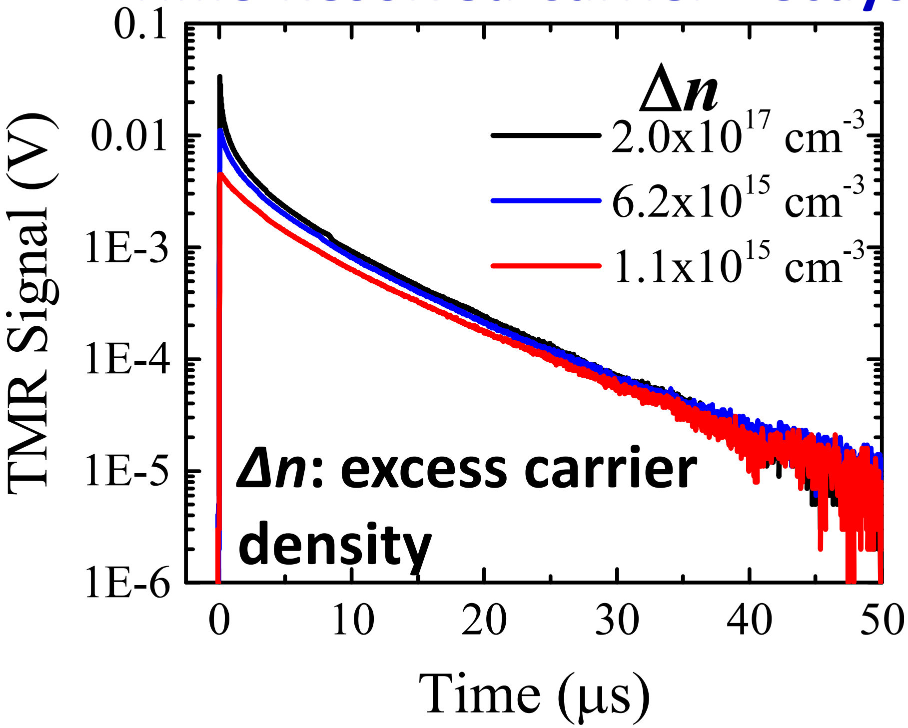
Time-Resolved Microwave Reflectance (TMR)



- **High sensitivity – *Δn* down to 10^{12}-10^{13} cm^{-3} (sample dependent)**
- **Accurate measurement of minority carrier lifetimes in low-doped material**
- **Fast acquisition and high throughput**
- **Roughly 3 ns time resolution**

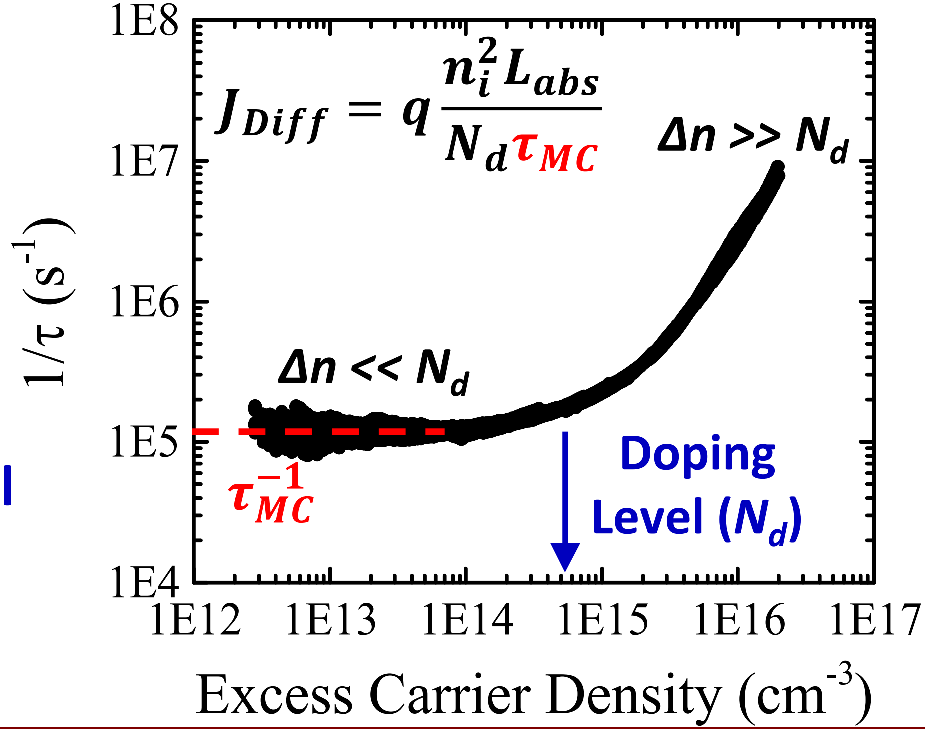
Time-Resolved Photoconductivity Decay

Time-Resolved Carrier Decays



$$\tau^{-1} \propto \frac{\partial(TMR)}{\partial t}$$

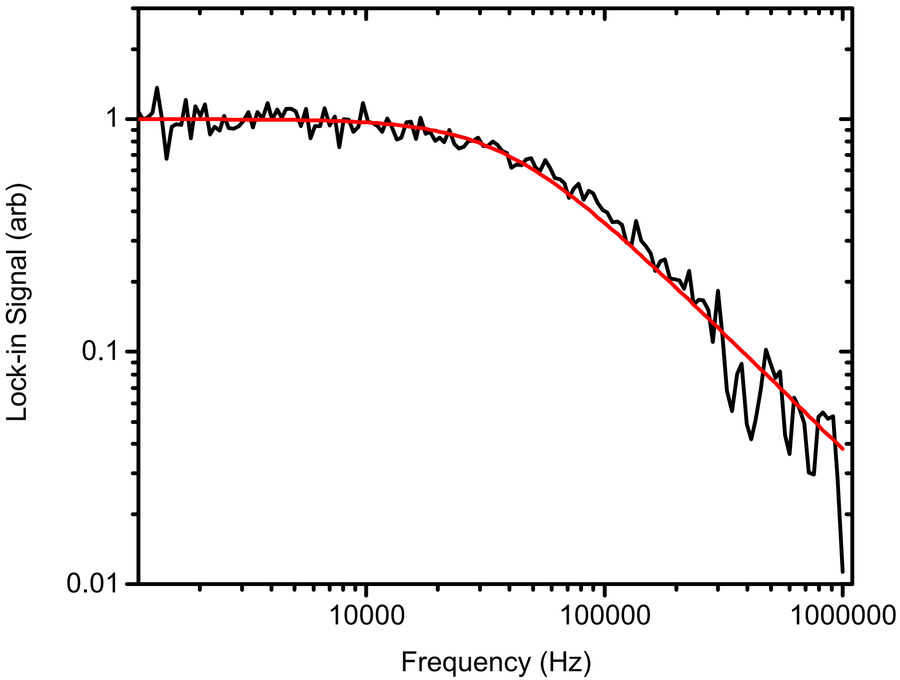
Instantaneous Inverse Lifetime



Time-resolved microwave reflectance (TMR)

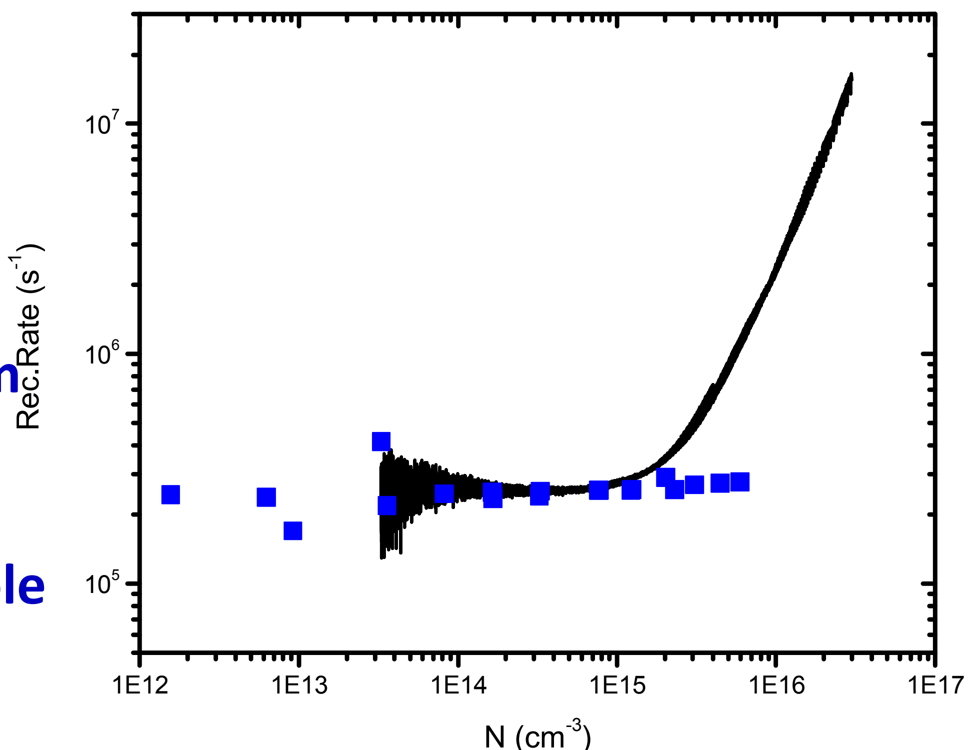
- Excess carriers injected using an optical pump pulse
- Temporal decay probed by change in microwave reflection off the sample

DC Modulated Photoconductance Response



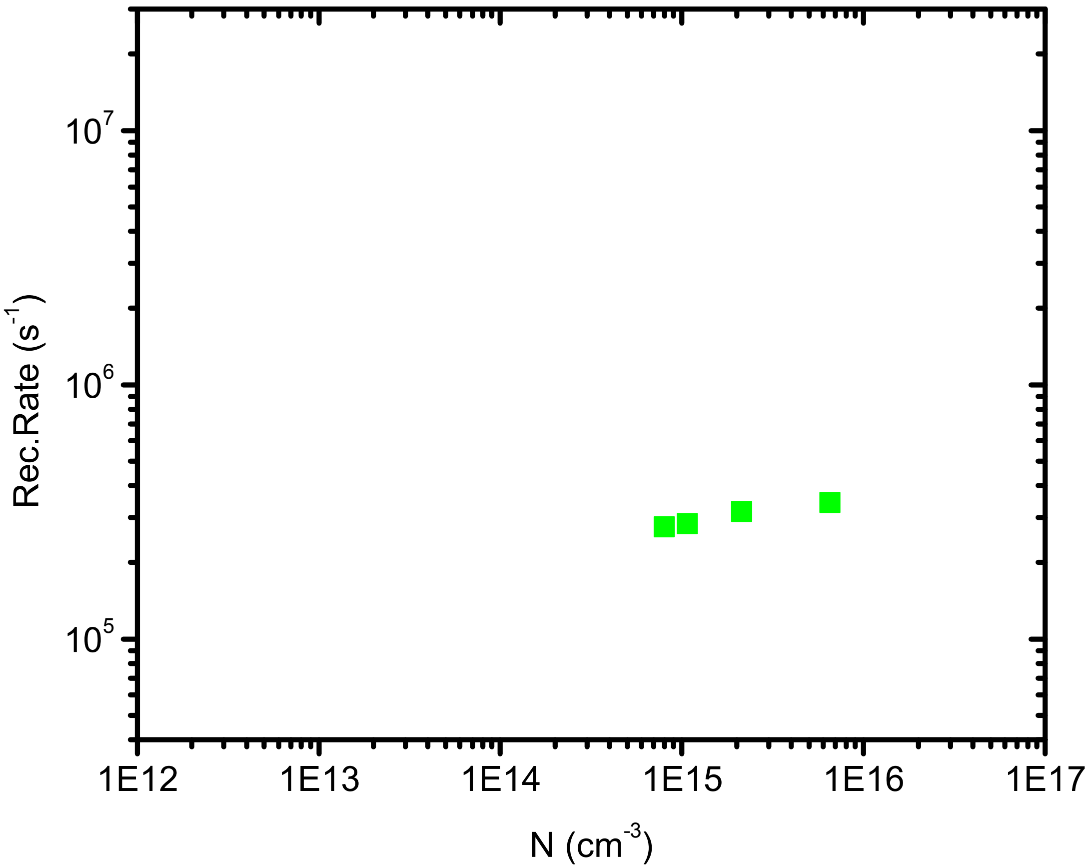
$$C(f) = \frac{1}{sqrt(1 + (2\pi * f * \tau)^2)}$$

Lifetime: $\tau = {}^{1}/_{2\pi f_{3dB}}$, $R = {}^{1}/_{\tau}$

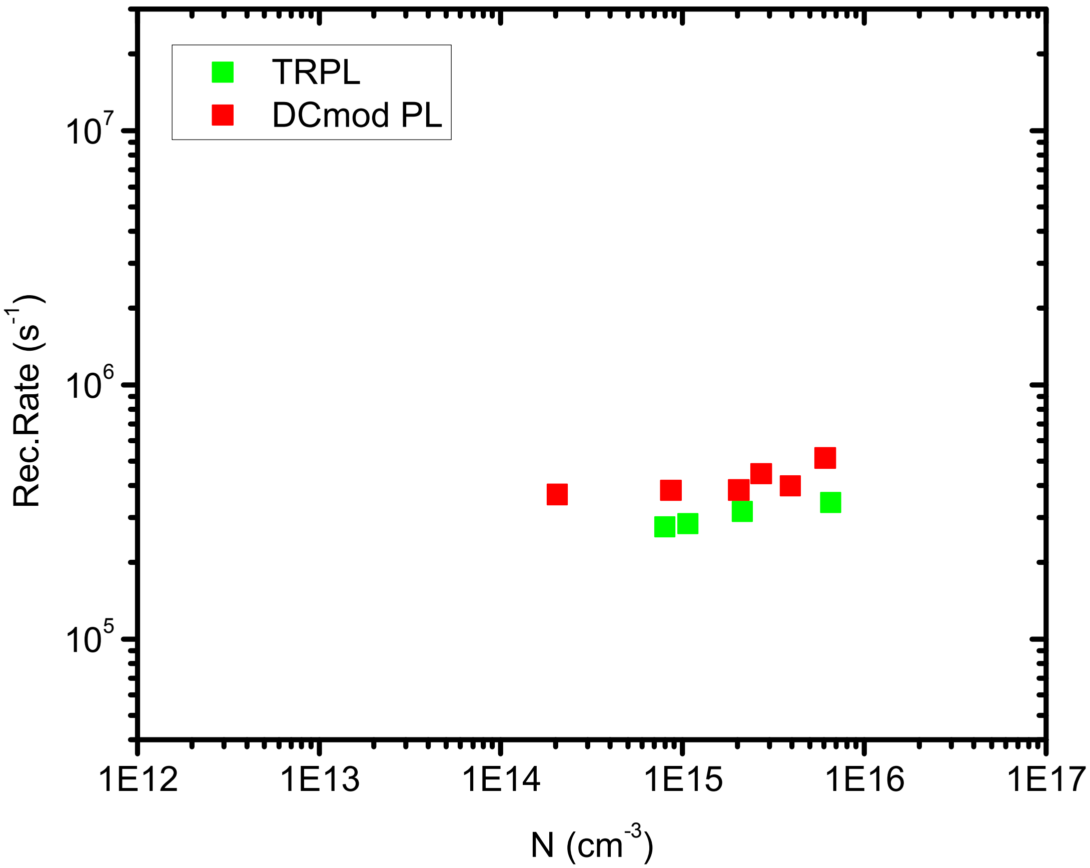


- **Excess carriers injected using 1625nm pump**
- **Signal roll off measured from change in microwave reflection off the sample**

Comparison

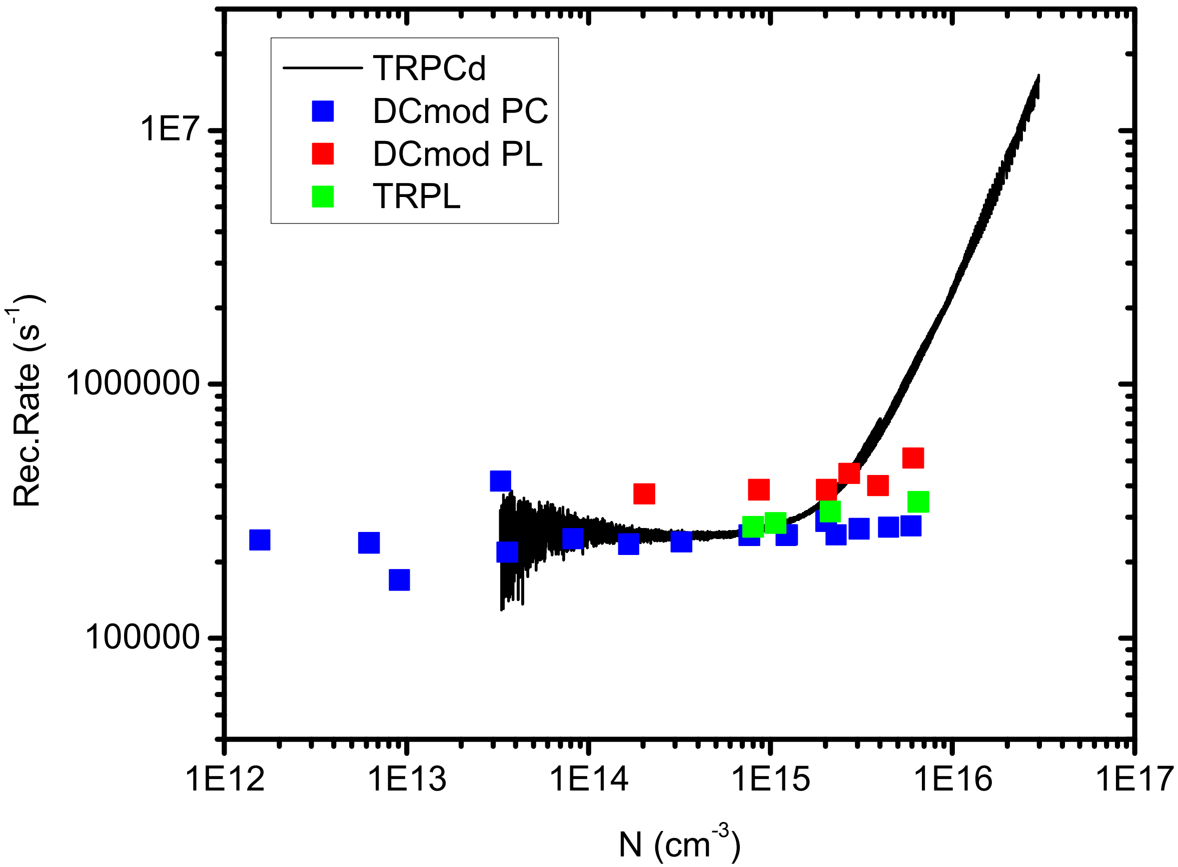


Comparison



TRPL
DCmod PL
Rec.Rate (s^{-1})
10^7
10^6
10^5
1E12
1E13
1E14
1E15
1E16
1E17
N (cm^{-3})

Comparison



TRPCd
DCmod PC
DCmod PL
TRPL
1E7
1000000
100000
Rec.Rate (s^{-1})
1E12
1E13
1E14
1E15
1E16
1E17
N (cm^{-3})

Conclusion

- Photoluminescent dependent measurements are a valuable means to measure marginally doped T2SL structures
- Photoconductive measurements have proven to be highly sensitive, opening a path for carrier lifetime measurements of minimally doped T2SL

Time-Resolved Photoconductivity Decay

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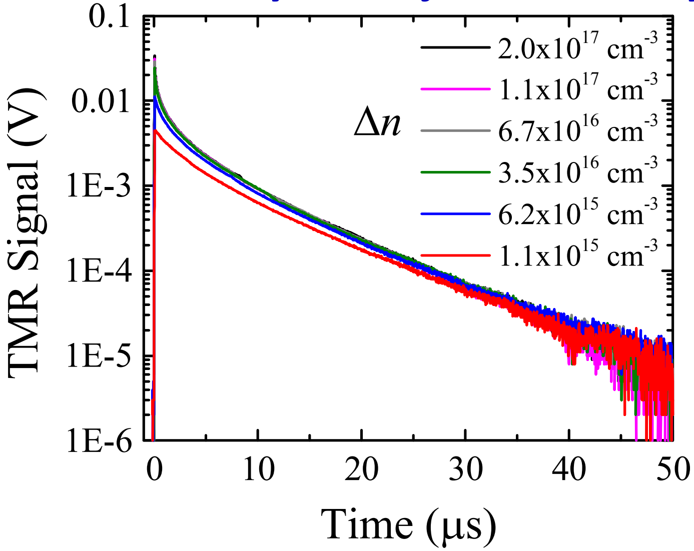
TMR Decays vs. Injected Density

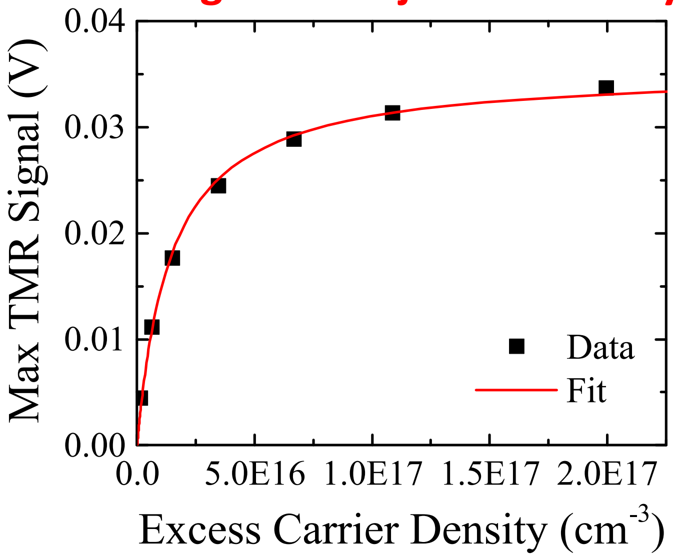


$$\tau^{-1} = -\frac{1}{\Delta n}\frac{\partial \Delta n}{\partial t} = -\frac{1}{\Delta n}\frac{\partial \Delta n}{\partial S}\frac{\partial S}{\partial t}$$

***Δn*: excess carrier density**

***S*: TMR signal**

Max Signal vs. Injected Density



Instantaneous Inverse Lifetime