Probing Band-Tail States in Silicon MOS Heterostructures with Electron Spin Resonance

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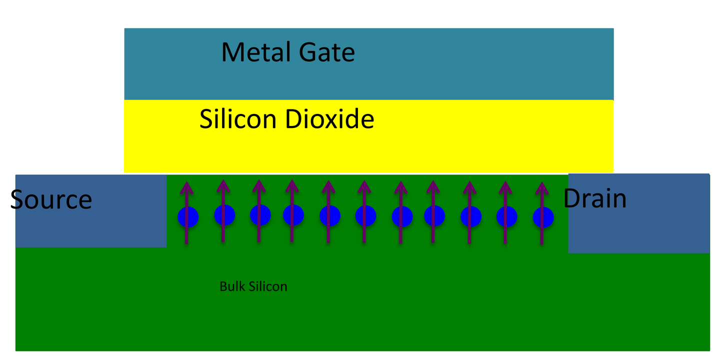
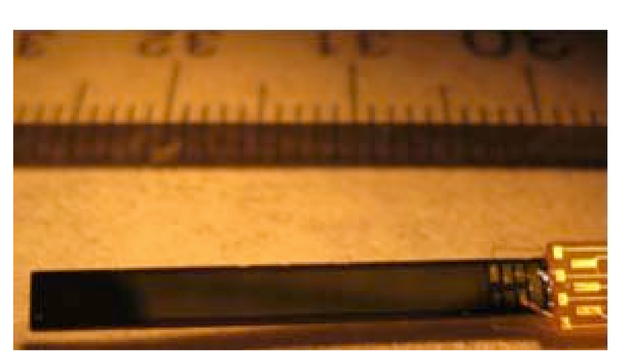
Introduction

Low temperature electron confinement in MOS heterostructures has taken on new importance with the rise of single electron quantum devices. Natural interface disorder induces potential fluctuations, which can localize single electrons with confinement energies of a few meV. Electron mobility is often used as a figure of merit to characterize interface quality in semiconductor devices, but may not tell the whole story for single electron quantum devices. We present a new method to characterize electrons trapped in band tail states at the Si/SiO_2 interfaces of MOS heterostructures.

Samples

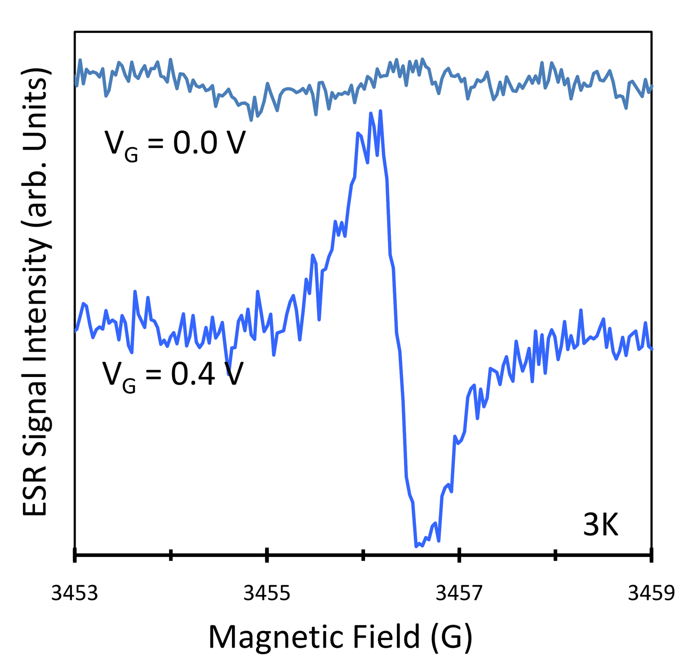




Sample	Description	Oxide thickness	V_{Th}	Peak Mobility (4K)
Sandia	Inversion	35 nm	0.3 V	10 000 $cm^2 V^{-1} s^{-1}$
Princeton	Accumulation	110 nm	1.0 V	14 000 $cm^2 V^{-1} s^{-1}$

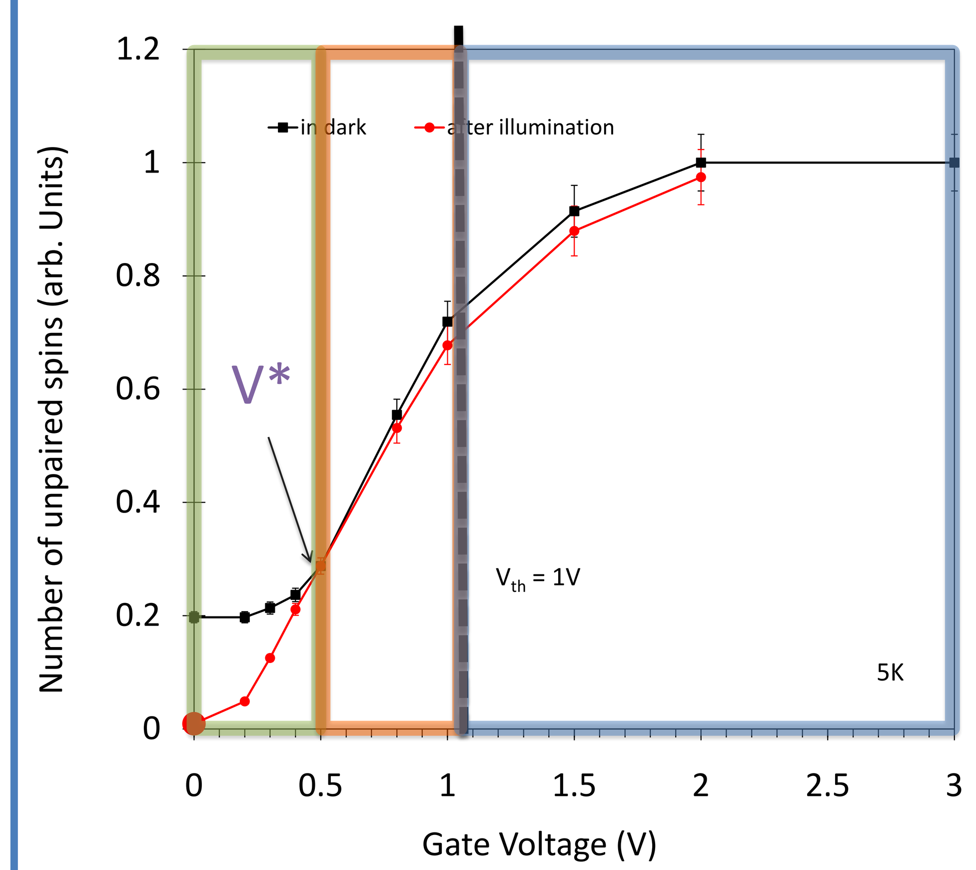
CW ESR Experiment

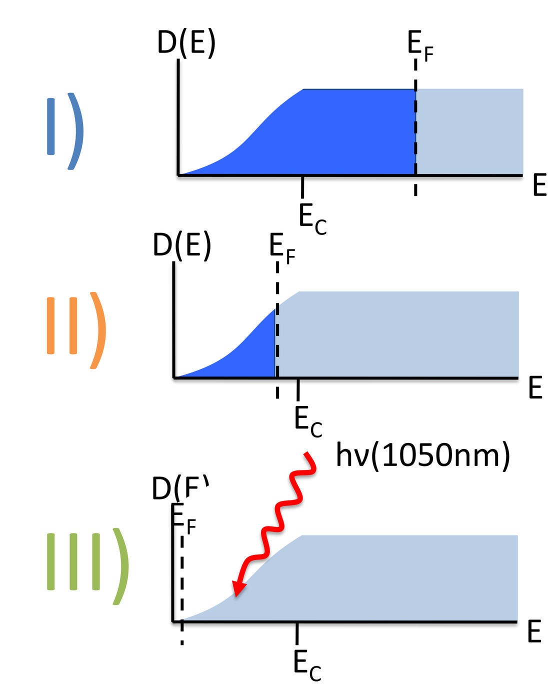
- Identified an ESR signal with a g-factor of 1.994 and a line width of 0.6 G
- The signal displays a strong gate voltage dependence
- Matches literature for 2D electrons in Si/SiO_2 and Si/SiGe heterostructures from ESR
- Matches EDMR



→ Signal from 2D Electrons

Gate Voltage Dependence





I) Above Theshold

- Mobile Electrons
- Signal independent of V_G

II) Below Threshold

- Electrons confined to disorder induced band-tail states
- Thermally emit

III) Far Below Threshold

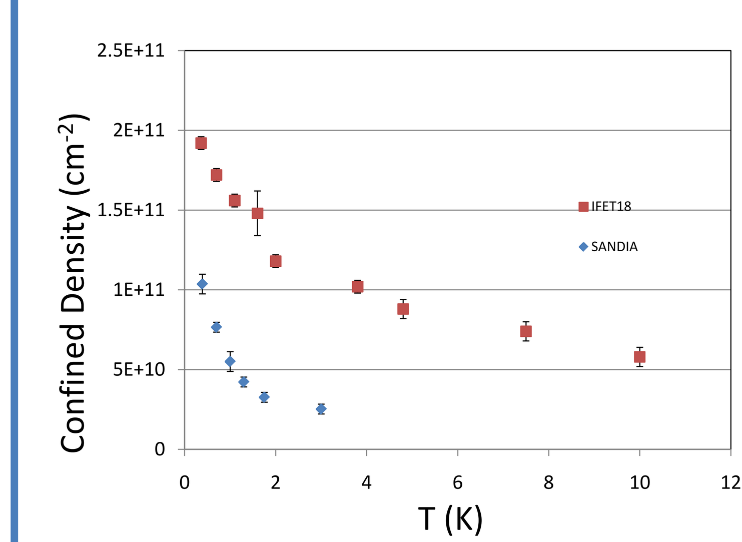
- Localized electrons at the Fermi surface no longer have sufficient thermal energy to escape from the potential minima
- Fermi Level pinned
- Signal independent of V_G

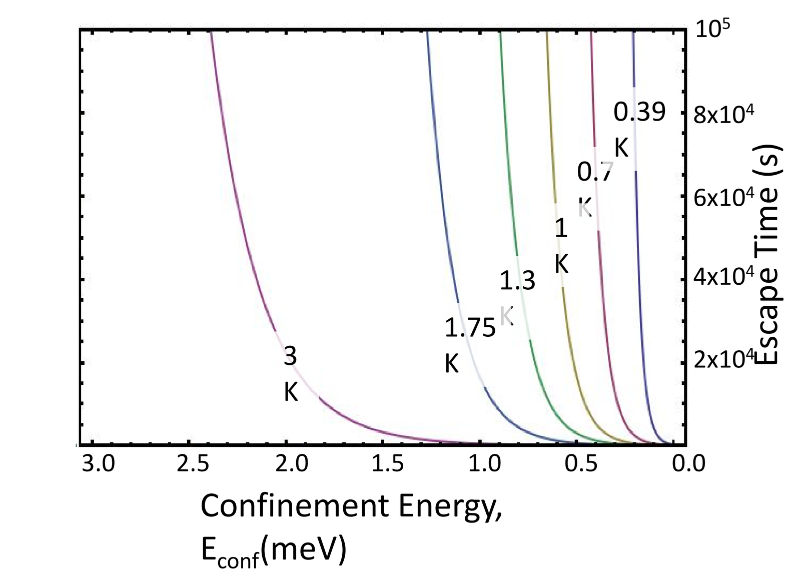
Illuminate

- Creates holes which neutralize electrons
- The electron quasi-Fermi energy is no longer pinned and we observe a decrease in confined electrons below V*

V* = the gate voltage at which the Fermi level is aligned with the energy of the shallow most states in the band-tail, which are unable to thermally detrap.

Depth and Density of Confined Electrons





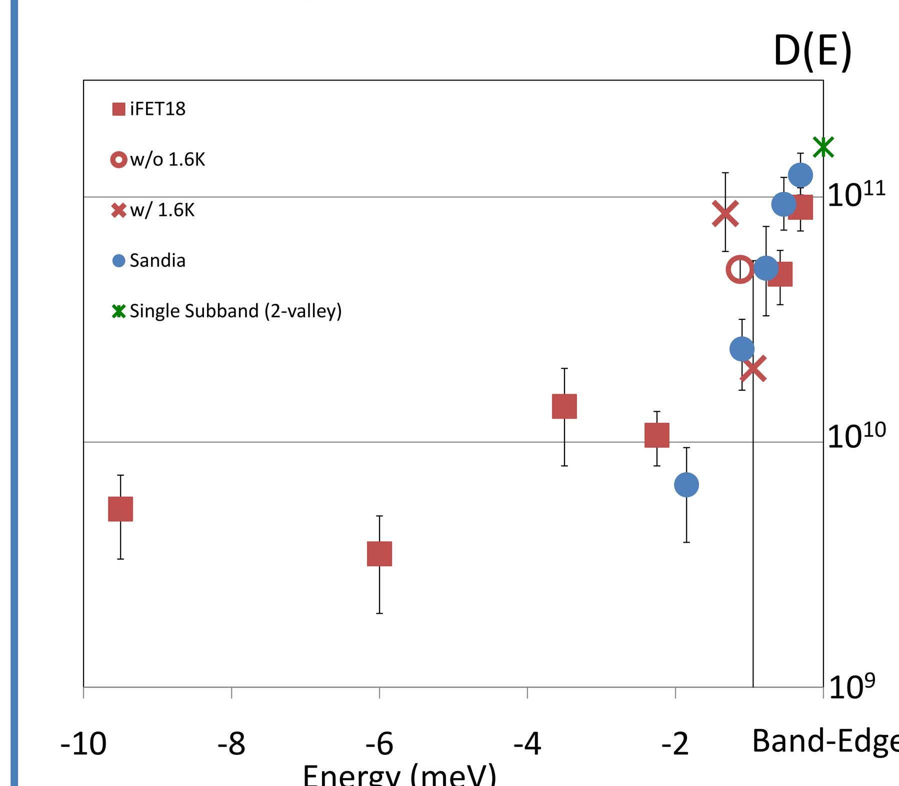
V* → Confined Density

$n^* = C_{ox} V^*$

Temperature → Confinement Energy

$\rightarrow \tau = \sigma \sqrt{\frac{U(E_{conf},T)}{2m^* n(E_{conf},T)}}$

Density of States in the 2D band-tail



$$D(E) = \frac{\Delta n_{conf}}{\Delta E_{conf}}$$

- Agrees with Calculated Band Edge DOS
- Sandia Device displays lower density of shallow localized states

Summary

- Measured band-tail DOS in two Si MOSFETs showing similar mobilities
  - Sandia devices displays shallower dot depth and smaller DOS
  - Suggest a higher quality for single electron quantum devices
- ESR can be used as a probe of 2D band-tail states
- ESR measurements offer a new means to characterize and study interface disorder in MOS heterostructures

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