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Numerical Model of the Optical Stark effect as a Mode-Locking Mechanism for Femtosecond VECSELs

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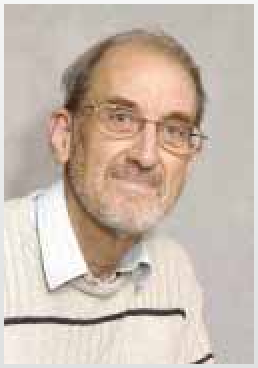
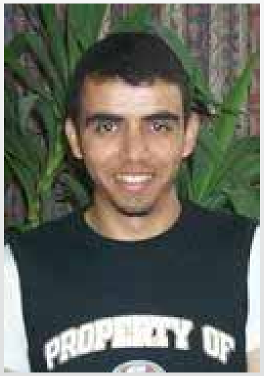
Talk Plan:

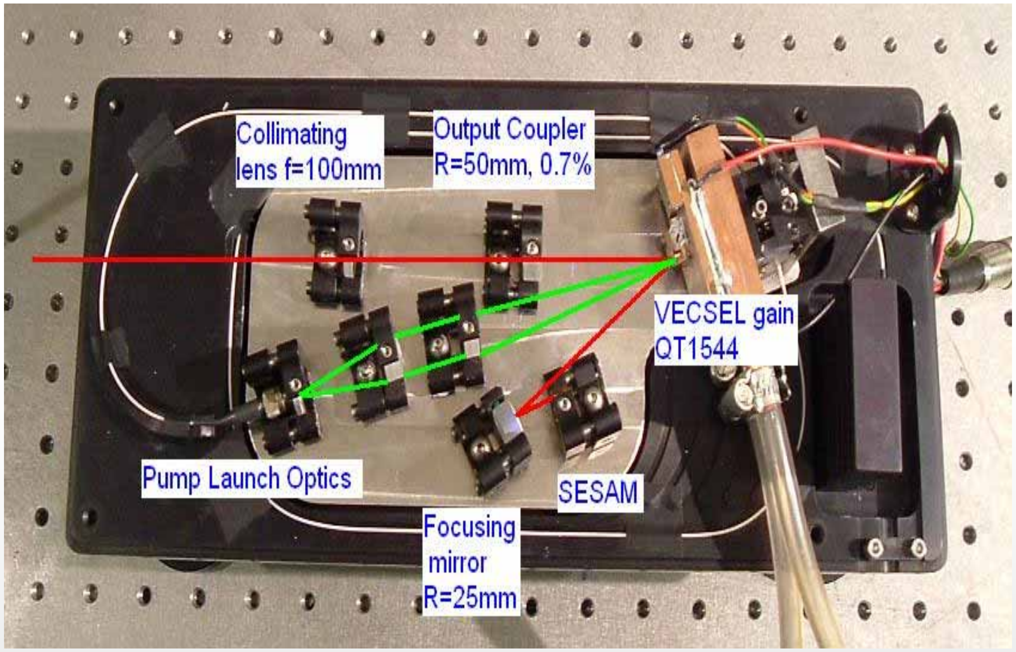
- VECSELS- Experimental Results
- Introducing the optical Stark effect
- Model description and assumptions
- Numerical results
- New experimental results

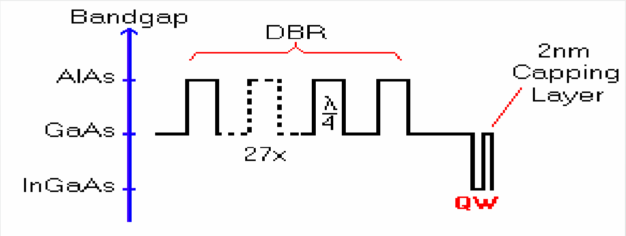




Stark Mode-locked VECSEL:

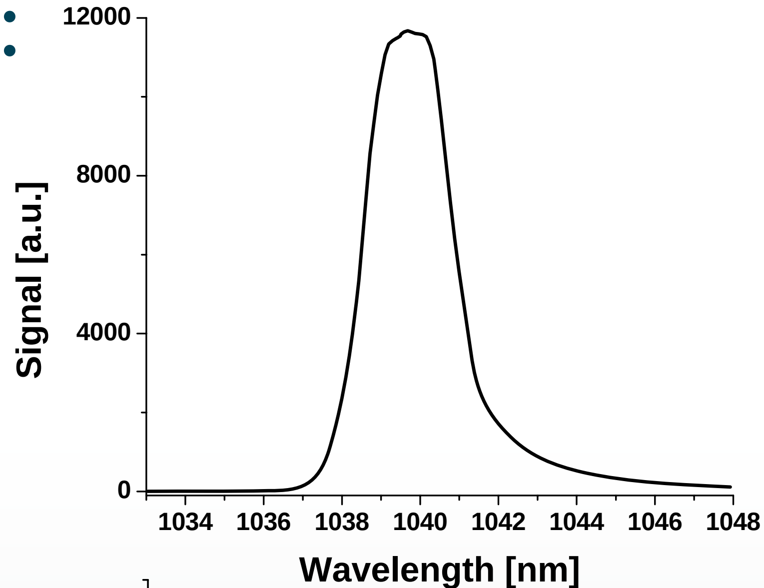
- Optically pumped semiconductor disk laser
- External cavity
- Gain bandwidth ~35nm
- Typical mode-locked bandwidth ~2.5nm

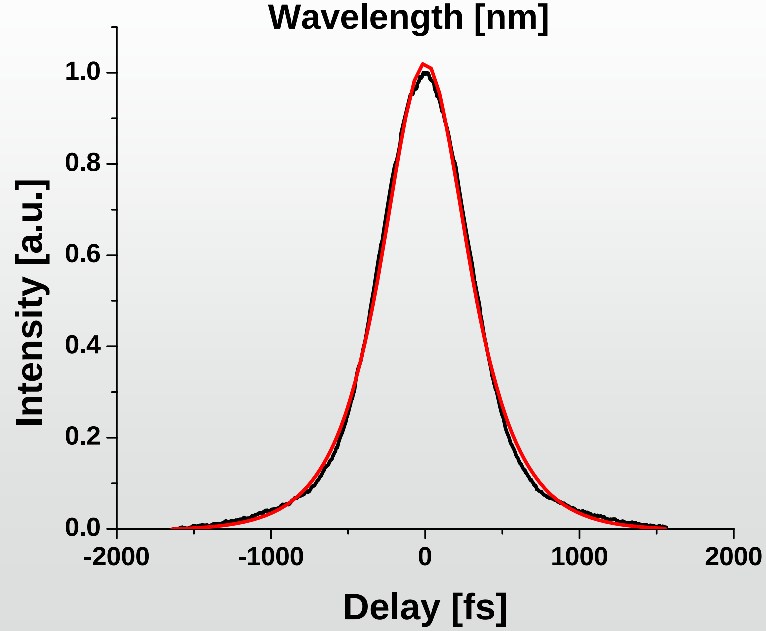




Mode-locked VECSELs:

- Experimental 450 fs
- Passively mode-locked by a semiconductor saturable absorber mirror (SESAM)
- Suggested optical Stark effect as mechanism
- A theoretical model is needed to confirm this





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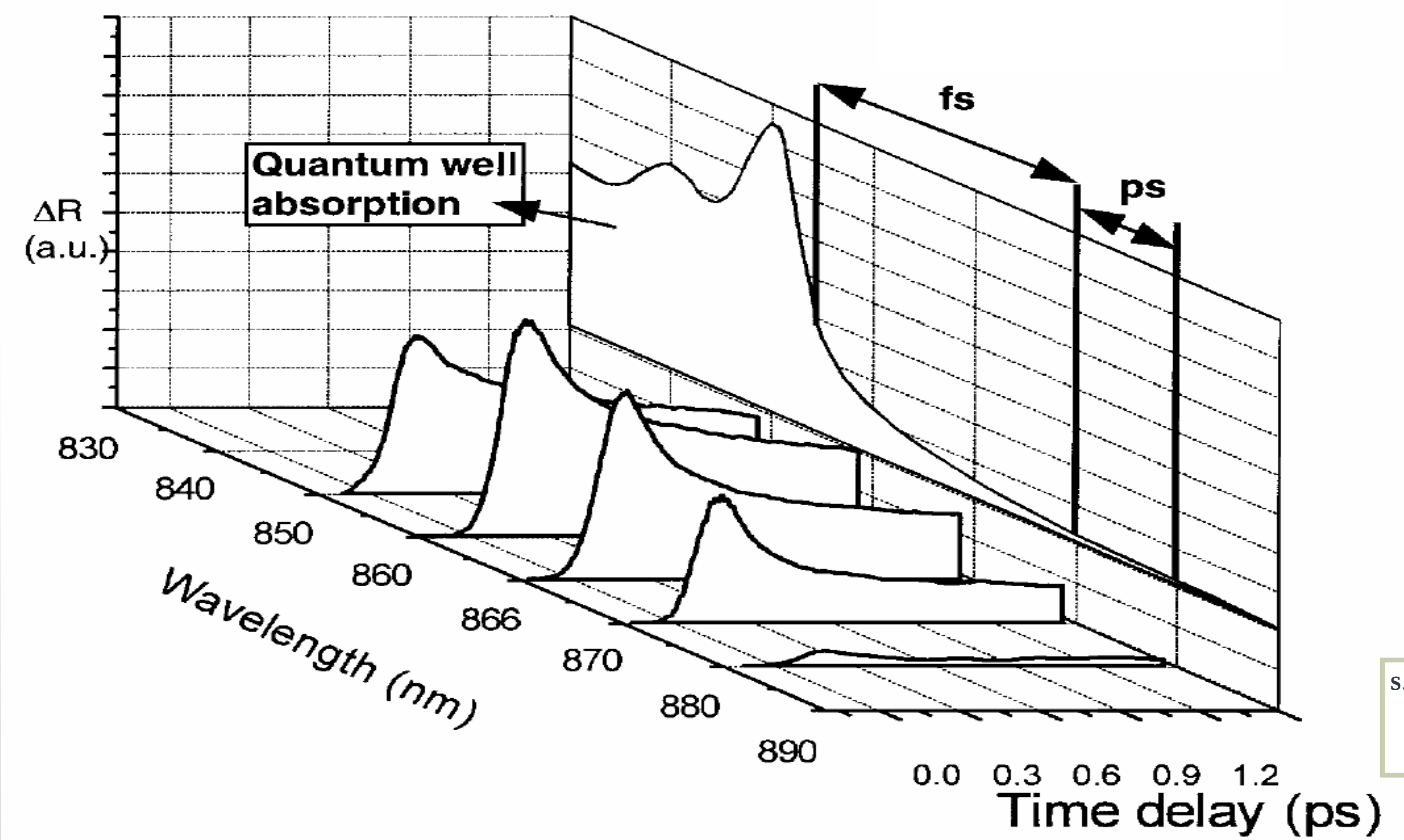
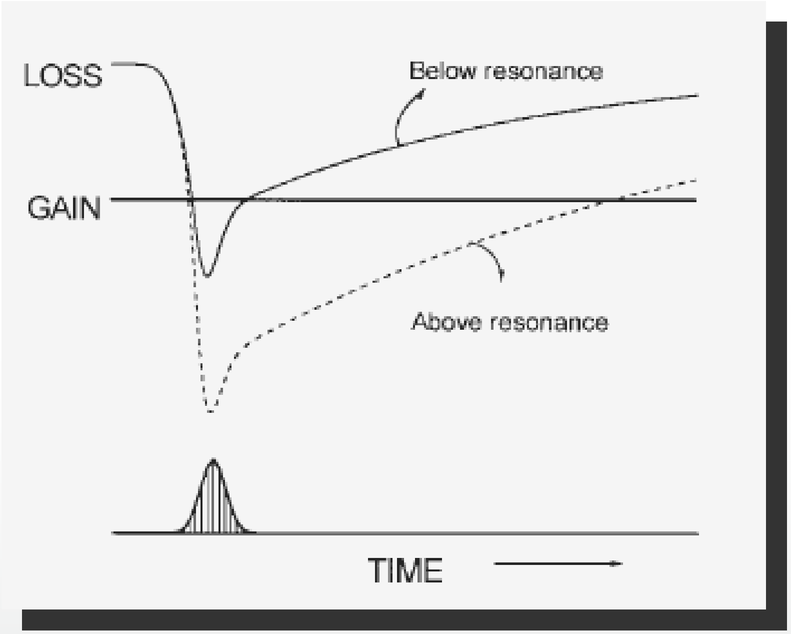
Optical Stark Effect in Quantum Wells:



S. Tsuda et al. IEEE J. Sel. Top. Quantum Electron. 2, 454 (1996)

Optical Stark Mode-locking:

- Phase shifts too small for soliton mode-locking
- Signatures of OSE:
  - VECSEL operates below exciton transition energy of the SESAM QW at (1025nm)
  - Optical Stark effect is a quasi-instantaneous nonlinear response (<100fs)



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Optical Stark Model Assumes:

- Intracavity pulse energy has stabilised
- Pulse profile and optical spectrum still evolving
- The pulse shortening effect is very small per transit
- Model looks at the final approach to steady state over many transits

Model of Stark Pulse Shaping:

- Homogeneous ensemble of 2-level atoms
- Ensemble relaxes to ground state between pulse transits
- Maxwell's equations determine transmission coefficients
- A generalised Lorentz equation

$$\dddot{P} + 2\alpha\left[\ddot{P} + \gamma^2 E^2(t) P\right] + \left[\omega^2 + \gamma^2 E^2(t)\right]\dot{P} = \omega_p{}^2 \dot{E}$$

Stark effect terms

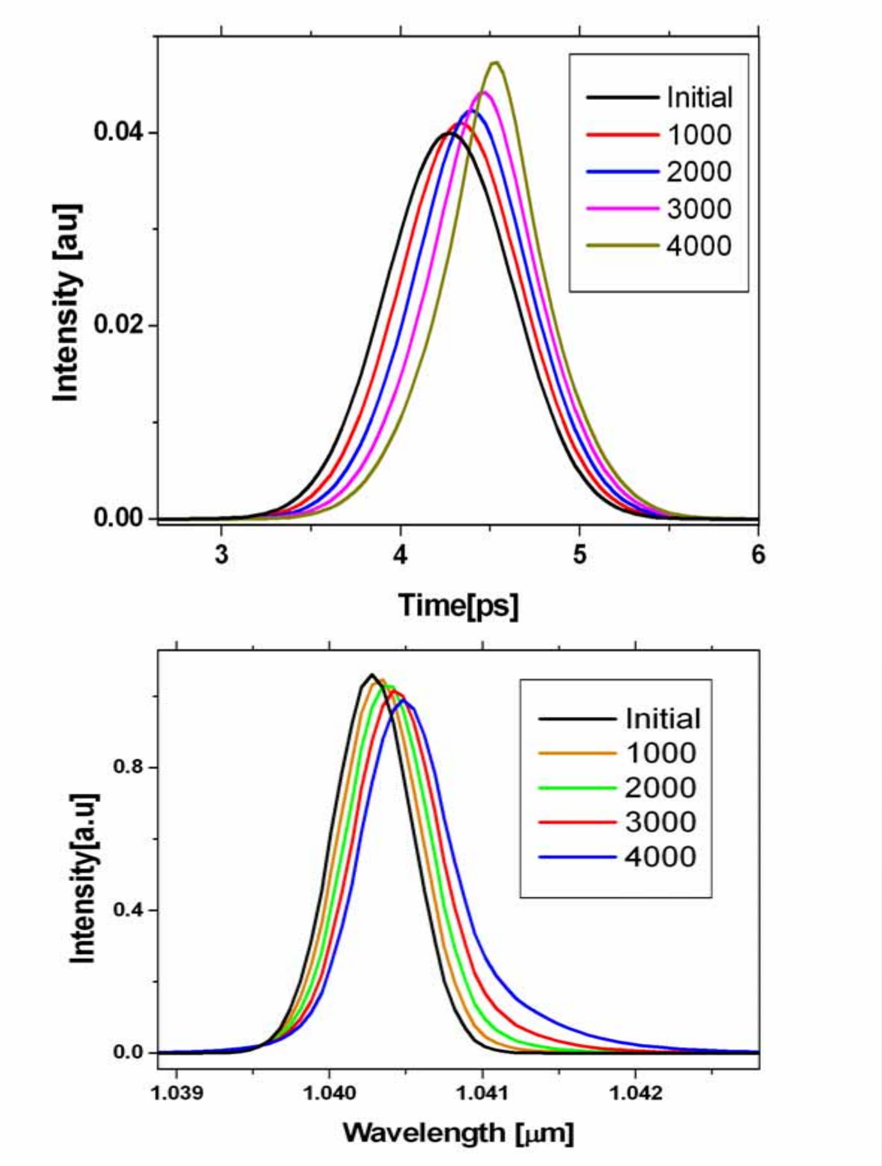
- Solutions found by iterations in the frequency domain

Pulse Evolution:

•Pulse evolution over 4000 transits

•Pulse shortens from 800fs to 480fs

•Asymmetric spectral broadening – Less absorption at the long wavelength tail



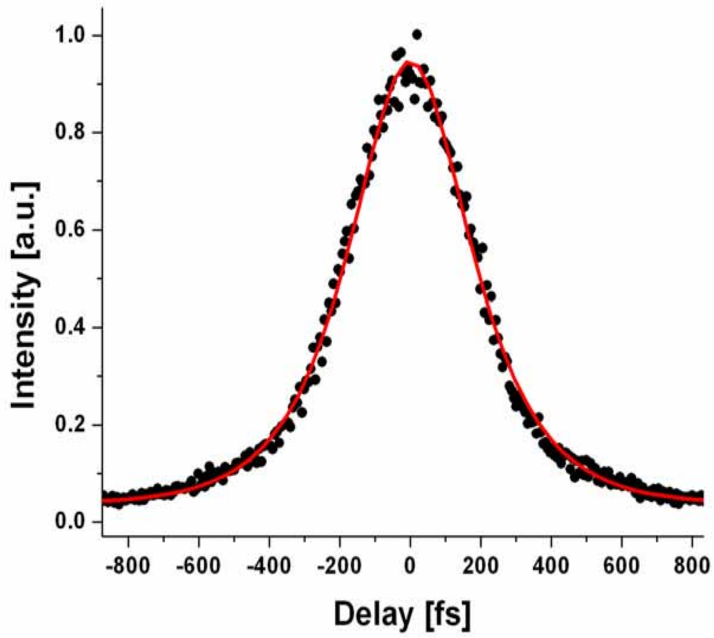
Theoretical Conclusion:

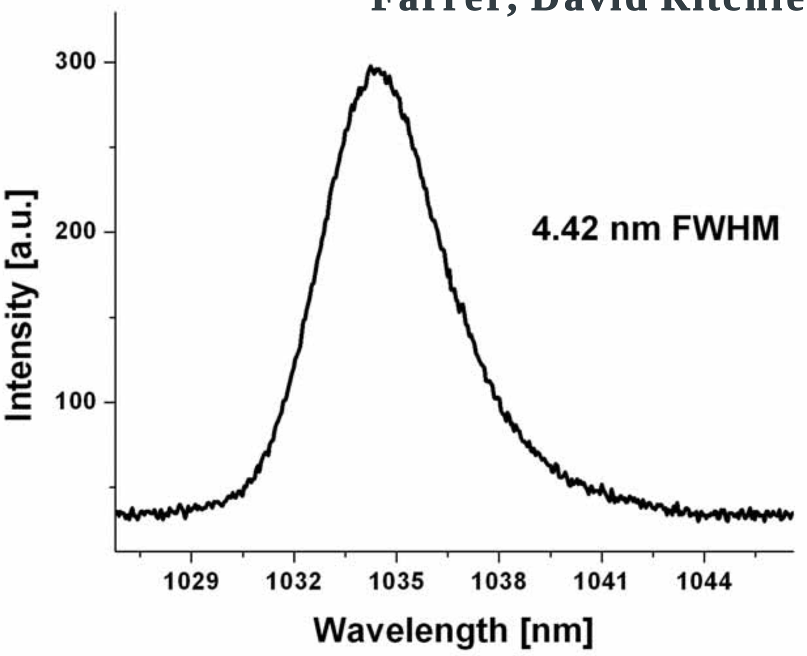
- Stark effect strength is consistent with experimental observations
- Effect is weak and broadband- Can occupy a large fraction of resonance width
- Future work includes applying a finite bandwidth filter and nonlinear phase shifts

Experimental demonstration

- 260fs transform limited pulses

SESAM grown at Cavendish lab, Cambridge by Ian Farrer, David Ritchie





- New SESAM with 2 times optical Stark effect strength used along the same gain structure
- Model shows further pulse shortening is possible