# ALL-OPTICAL COMPONENTS USING CLOSELY COUPLED LASERS

**E. Clerkin[1,2]*, E.P. O'Reilly[1,2], and A. Amann[1,3]**

[1]*Tyndall National Institute, Lee Maltings, Cork City*
[2]*Physics Department, University College Cork*
[3]*School of Mathematical Science, University College Cork*

* *Contact Author: eoin.clerkin@tyndall.ie*

**The realisation of** stable, fast and scalable all-optical components would significantly increase the scope of photonic devices and has therefore attracted considerable interest in the laser community. In the recent literature many all-optical logic gate and all-optical memory element candidates were proposed including those using hetero-structure photonic crystal lasers [1], coupled micro-ring resonators [2], and injected two mode semi-conductor lasers [3]. Here, we present several surprisingly simple designs for all-optical logic gate and all-optical memory elements which are based on two closely coupled single mode lasers.

Two semi-conductor laser diodes, mutually coupled via light of each entering the cavity of the other after a small delay, were modelled by a system of non-linear rate equations. Using a new reduced model, a bifurcation diagram was obtained by varying the coupling strength and coupling phase. This separated parameter space into regions of distinct dynamics. Symmetry-broken 1-colour states were shown to be stable, where each laser has significantly different intensity but are locked to the same single frequency (see figure 1). Symmetric and symmetry-broken 2-colour states were also found and explained as slow-fast dynamical behaviour. Due to the ability to exchange both lasers, symmetry-broken states always exist in pairs. Overlap with regions of symmetric 1-colour states creates regions of tri-stability.

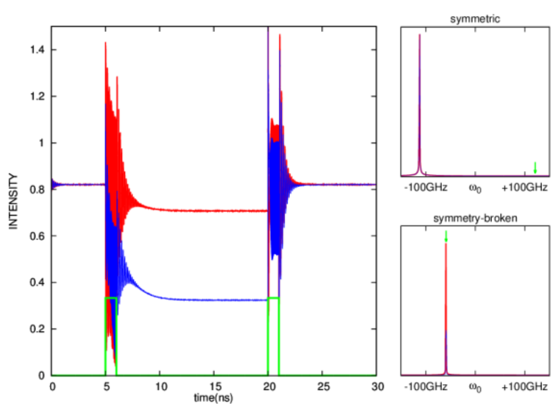


**Figure 1.** Time traces and Fourier spectra for laser one (red) and laser two (blue). Green arrows and line shows the injection time, strength, duration and frequency.

Knowledge of the bifurcation boundaries allows us to suggest two NOR gate candidates. For these we required a frequency to be turned off when either input channel is on. Switching is achieved all-optically via a master laser, with the input channels defined as each laser in example one and defined in frequency space in example two.

Memory units require at least two stable states and a mechanism to switch between them. We propose two examples based on multi-stabilities in 2-colour states. Switching is achieved optically with a master laser using two different injection scenarios. Figure 1 shows a third example of all-optical memory element which uses a bi-stability in frequency and amplitude between symmetric and symmetry-broken 1-colour states. Switching is achieved via optical injection from a master laser injecting into laser one. Initially the two lasers start in a degenerate state with the same intensity. Using a pulse of a positive detuning relative to the free running frequency, the symmetric state symmetry breaks. As the frequency and intensity changes, the on and off states can be easily distinguished, which is desirable from an application point of view. To switch back a pulse of negative detuning is injected into one of two lasers.

The high degree of multi-stability discovered enables many designs. As the multi-stabilities and bifurcations persist in the limit of zero delay, the distance between the lasers can be reduced as far as technologically possible. Memory units and logic gate of this kind are therefore open to miniaturization and allow integrability. Closely coupled lasers offer a promising approach for the realisation of scalable and fast all optical components.

## References

[1] C.H. Chen et. al., *All-optical memory based on injection-locking bistability in photonic crystal lasers*, Opt. Ex. **19** (2011).

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