Chaos Synchronization of Unidirectionally Coupled Multisection Lasers

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Abstract *The synchronization properties of two coupled multisection lasers operating in the chaotic regime are investigated. The strong dependence on the pasive sections currents makes these devices ideal candidates for on/off phase shift keying encryption.*

Introduction

Chaos-based communication can be considered as an alternative technique to encode and transmit information at high bit rate in conventional optical communication systems. Recent experiments in an installed optical fibre network have stressed the potential of this technique [1]. Within a chaotic carrier, the information can be encoded in different ways, the most common ones being chaos shift keying, amplitude chaos masking, and chaos modulation. As an alternative to these traditional schemes, a new promising encryption method termed on/off phase shift keying (OOPSK) has been proposed recently [2,3]. This technique requires two external cavity semiconductor lasers operating in a chaotic regime unidirectionally coupled in a master-slave configuration. If the external cavities of the master and slave lasers are identical, the two chaotic outputs synchronize giving rise to a high correlation coefficient. However, if the two cavities differ within sub-wavelength precision then synchronization quality degrades [2]. By periodically, or aperiodically, changing slightly the external cavity of the master laser, the slave becomes synchronized (high correlation coefficient) or unsynchronized (low correlation coefficient) with the master. These two states, synchronized and unsynchronized, allow us to define two bits, ``0'' and ``1'' [3]. Numerical calculations reveal that the maximum rate at which information can be encrypted with the OOPSK method depends on the re-synchronization time when the system moves from an unsynchronized stated to a synchronized one. This re-synchronization time depends, as well, on the round-trip time in the external cavity [4]. Consequently, external cavity semiconductor lasers would only allow for maximum bit rates of few hundred of Mbit/s [3]. This limitation could be overcome by using configurations with much shorter feedback paths.

In this work we consider the limit of ultra-short optical feedback [5] with delay times of only few ps. This regime is achieved by integrating the feedback path into the semiconductor laser in the framework of a multi-section structure. The result is a compact and robust device, shown in figure 1, which, in addition to the short time scales, is an important requirement for possible applications. Multisection lasers are indeed expected to be essential sources for high bit rate OOPSK encryption.

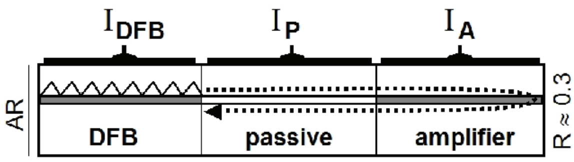

Figure 1: Schema of a laser with integrated optical feedback. AR: antireflection coating. DFB: 1.55 μm distributed feedback laser. Passive: section composed of a material with higher bandgap. Amplifier: integrated 1.55 μm amplifier section with an end reflectivity of about 30%.

Results

Under appropriate operating conditions these three section lasers emit chaotic power with its associated broad spectrum. We shall demonstrate that under these circumstances synchronization of two chaotic lasers takes place beyond a certain coupling strength. We shall also show a strong dependence of the synchronization quality on the detuning $\Delta\phi_P$ between the phase shifts in the passive sections of the master and slave laser, which makes these devices excellent potential sources for OOPSK encryption.

We numerically study these devices by using a comprehensive travelling-wave model that is carefully described in Ref. [5]. It resolves the spatio-temporal photon-carrier dynamics along the overall cavity of the multisection lasers, including multiple reflections at facets and Bragg gratings. This model is used to search and characterize regimes of chaotic operation. Our work gives representative results for the amplifier current I_A=80 mA. All parameters are at the values of Ref. [5] except the linewidth enhancement factor α =-3 in the amplifier.

Under these conditions, the emission of the device is always chaotic for all phase shifts ϕ_P. Representative time trace and power spectrum of a single device are shown in figure 2 a) and b) respectively. Large irregular pulsations can be observed in the optical power while the spectrum is broad and flat except for few peaks.

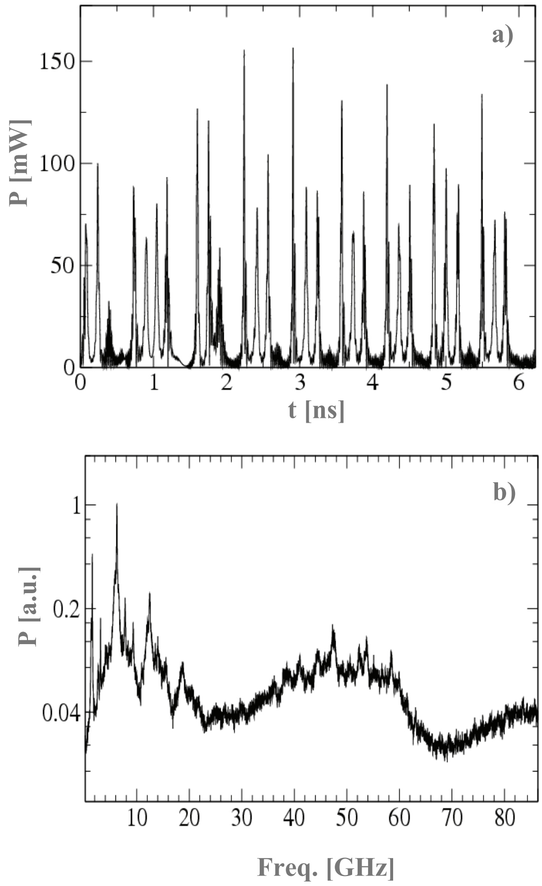

Figure 2: a) Representative time trace. b) Power spectrum of chaotic emission.

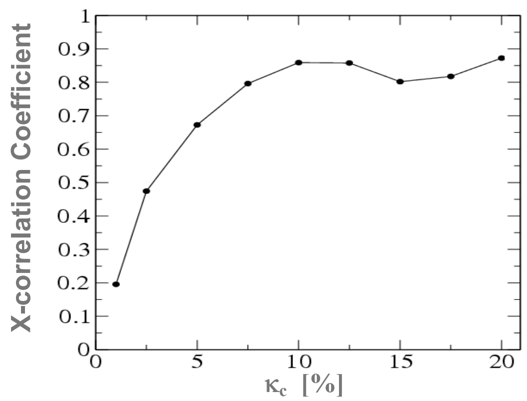

Figure 3: Dependence of the cross correlation coefficient on the coupling strength.

Once a well developed chaotic regime is identified, two identical devices are coupled in a master-slave configuration.

To quantify the degree of synchronization, we calculate the maximum of the cross correlation function between master and slave outputs. Synchronization is expected to depend on the coupling strength k_c, which is the percentage of the master emission coupled into the slave. The results are presented in figure 3. For low values of k_c we observe uncorrelated chaotic outputs even until identical operation characteristics. For intermediate coupling strengths synchronization improves until large correlation is obtained for large k_c,

To check the potentiality of this configuration for the OOPSK encryption we have to analyze the dependence of the synchronization degree on the difference $\Delta\phi_P$ of the feedback phase shifts between master and slave lasers. In figure 4 we plot the maximum of the cross correlation function vs. $\Delta\phi_P$. A variation of about 30% to 90% can be seen, a sufficiently high contrast for OOPSK encoding.

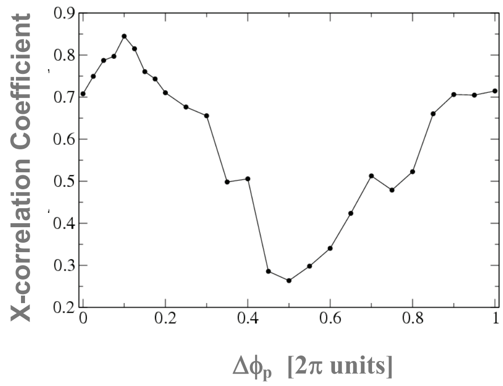

Figure 4: Cross correlation coefficient vs. the detuning

Conclusions

In conclusion, we have demonstrated that two multisection lasers coupled in a master-slave configuration are excellent potential sources for on/off phase shift keying encryption. Under appropriate coupling strength between master and slave systems we obtain a maximum of the correlation coefficient of about 90% and a minimum of about 30%. This contrast is sufficiently high to perform an adequate OOPSK modulation.

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