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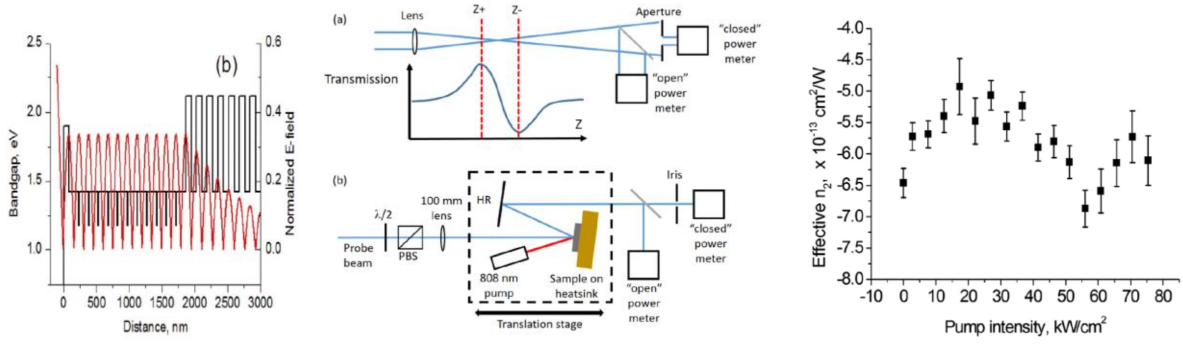
Abstract: Over recent years the dream of 100-fs pulse duration, kW peak power mode-locked pulses directly from semiconductor disk lasers (SDLs) has become a reality. To reach this performance level many effects need to be accounted for. In our recent work we characterised the nonlinear lens in the active medium which can play an important role in some of the mode-locking mechanisms. DBR-free semiconductor disk lasers are another new variant of SDL technology which offers less design restrictions compared to traditional SDLs. Their design and recent record CW performance will be discussed.

Optically pumped SDLs are a type of semiconductor laser which takes a hybrid approach, combining a semiconductor gain material, which gives the advantages of bandgap engineering, with the cavity architecture and optical pumping more commonly seen in diode pumped solid state lasers, enabling power scaling, excellent beam quality, intracavity frequency conversion and mode-locking [1].

Few-hundred femtosecond pulse operation is relatively straightforward using a SESAM and designing the gain structure for low dispersion and low gain filtering. Multi-kW peak powers with ~400 fs pulses have been reached using this approach [2]. It was shown that SDLs had the potential to produce sub-100-fs pulses, but that carrier dynamics become increasingly important as the pulse duration approaches the carrier-carrier scattering time in the gain structure [3]. Recently, sub-100-fs pulses with near-kW peak powers have been directly produced [4].

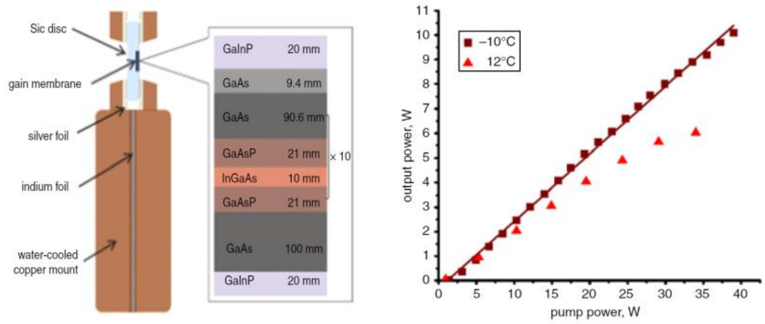
Nonlinear lens driven self-mode-locking has been reported on a number of occasions but the mechanism was not experimentally verified [5, 6]. We therefore characterised the intensity dependent nonlinear lens in a pumped SDL gain structure under a range of conditions. We characterised the nonlinear lens of an anti-resonant 10 QW gain structure designed for an operating wavelength of 1035 nm using a z-scan measurement technique with a 340 fs pulse fiber laser as our probe laser whilst simultaneously pumping the gain structure using an 808 nm fiber coupled diode laser.



Left: A schematic of a typical SDL gain structure. Centre: Schematic of Z-scan measurement setup to measure n_2 of the SDL gain structure with femtosecond probe pulses and under optical pumping. Right: Measured n_2 as a function of pump intensity.

We demonstrated that under a broad range of operating conditions a significant negative nonlinear lens is formed in mode-locked SDLs. This has the potential to drive self-mode-locking and should be taken into account in femtosecond pulse SDL design. Of particular interest is the small variation of the nonlinear lens as a function of pump power, indicating that the effect could be used as a robust mode-locking mechanism which is largely independent of pump power [7].

A recent alternative to the ‘gain mirror’ design of SDL is the DBR-free SDL. This has been developed to remove the need for the semiconductor DBR, which causes significant thermal resistance and in some material systems provides complex growth and narrow reflection bands. The removal of the DBR from the design has advantages including theoretically better heat removal from the structure and a different set of design rules which allows more flexibility in choosing the gain region properties such as overlap of E-field with quantum wells and microcavity filtering. We developed a 1000 nm DBR-free SDL in collaboration with Micheal Jetter’s group at the University of Stuttgart and were able to achieve record slope efficiency and output power of 27.5% and 10.1W respectively [8]. We have also demonstrated a DBR-free SESAM design which was used to mode-lock a standard VECSEL.



Left: A schematic of a DBR-free SDL and a typical mount. Right: Measured output power as a function of pump power for 1-micron DBR-free SDL at two heat-sink temperatures.

Conclusion: Semiconductor disk lasers offer a technology platform which combines the flexibility of semiconductor gain materials with the performance of diode pumped solid state lasers. High performance mode-locking can be achieved and we have shown that there is a significant nonlinear lens inside the gain structure which may enable self-mode-locked operation. We have also developed high power DBR-free SDLs which hold great potential for high performance devices at difficult wavelengths and for ultrashort pulse generation due to their different design architecture.

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