Ultrabroadband ring oscillator for sub-10-fs pulse generation

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A four-mirror ring cavity formed by chirped dielectric mirrors is proposed for self-mode-locked solid-state lasers. It offers, for the first time to our knowledge, the potential for approaching the gain-bandwidth limit in Ti:sapphire and related broadband lasers. Using this concept, we produced nearly bandwidth-limited 7.5-fs pulses from a feedback-initiated, self-mode-locked Ti:sapphire ring oscillator. Our experiments provide new insight into the physics and limitations of sub-10–fs oscillators.

The performance of prism-controlled lasers operating in the 10-fs regime[1,2] has been limited by the finite high-reflectivity bandwidth of quarter-wave dielectric mirrors and by the finite constant group-delay-dispersion (GDD) bandwidth $\Delta\nu_{\mathrm{GDD}}$ of the oscillator. Chirped multilayer dielectric mirrors[3] used for both feedback and intracavity dispersion control (mirror dispersion control, MDC) in femtosecond oscillators promises to push the current limits of ultrafast laser technology. However, linear cavities, in which the MDC concept was previously implemented[4] suffer from a few severe shortcomings, preventing full exploitation of the potential of the MDC technology for ultrashort pulse generation. Recently the MDC concept was implemented in a ring cavity.[5] We show that innovations in the cavity design and the chirped mirrors potentially will allow self-mode-locked MDC ring oscillators to approach the gain-bandwidth limit in Ti:sapphire and other broadband vibronic lasers.

A major limitation in linear-cavity short-pulse oscillators stems from the limited bandwidth of a low-transmittivity multilayer output coupler. The other principal drawback of a linear cavity lies in the fact that a thin wedged glass plate, which would be needed in a MDC oscillator for fine tuning the intracavity dispersion, severely impedes the start-up of passive mode locking because of étalon effects.

To overcome these shortcomings we have developed a MDC ring oscillator with a thin, highly doped Ti:sapphire crystal (path length 1.95 mm) as the gain medium. Recent progress in chirped-mirror technology permitted the fabrication of dichroic chirped mirrors that are transparent at pump wavelengths of 488 and 514 nm. As a result, an all-chirped-mirror cavity could be constructed for what we believe to be the first time. The 175-MHz ring cavity shown in Fig. 1 is formed by four chirped mirrors, which are selected for maximum $\Delta\nu_{\mathrm{GDD}}$.

Output coupling can be realized by use of a low-reflectivity coating deposited onto a slightly wedged (≈1.6°), thin (≈0.1−0.8-mm) quartz substrate, which is placed at Brewster's angle in the cavity. In contrast to a linear cavity, a low-reflectivity output coupler does not compromise the efficiency by producing two outputs because Kerr-lens mode locking (KLM) is unidirectional.[5,6] Angular dispersion introduced by the output coupler substrate is compensated by an identical uncoated compensation plate placed in close proximity to the output coupler. Translation of this plate provides a simple means of controlling the cavity GDD. Owing to feedback initiation of pulse formation,[6] the presence of thin plates does not inhibit the buildup of passive mode locking as is often the case in linear resonators. As a consequence, the ring cavity design shown in Fig. 1 removes the shortcomings of previously realized linear systems.

Following the design guidelines of Lin *et al.*,[7] KLM is accomplished with an aperture ≈20 cm apart from M1 in the collimated section of the resonator with the curved mirrors adjusted to the far boundary of the stability range. To our knowledge, this is the first demonstration of hard-aperture KLM in a ring laser. Previously, the soft gain aperture was utilized for KLM in Ti:sapphire ring oscillators.[5,6,8] We were also able to achieve soft-aperture mode locking; however, in the sub-10-fs regime the use of the hard aperture provided much more stable and much more reliable operation. We initiated femtosecond pulse formation by feeding back the output resulting from the radiation that circulates clockwise in the free-running laser as demonstrated by Pelouch *et al.*[6]

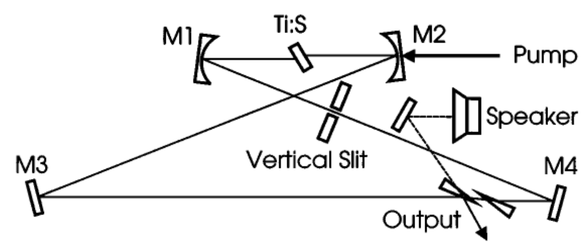

Fig. 1. Schematic of the MDC Ti:sapphire (Ti:S) ring laser. The pump beam is focused with a 40-mm lens onto the Ti:S crystal. M1, M3, M4, chirped mirrors; M2, chirped dichroic mirror. The radius of curvature of M1 and M2 is 50 mm.

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