Titanium:sapphire-on-insulator microresonator laser

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Abstract: We develop a titanium:sapphire-on-insulator integrated photonic platform and demonstrate a thin-film chip-integrated microdisk laser. The microresonators feature optical quality factors exceeding 1 million, enabling a sub-milliwatt lasing threshold. These results pave the way for low-cost, compact, chip-integrated titanium:sapphire lasers.

Introduction

Since its first demonstration in 1982, the titanium:sapphire laser [1,2] has enabled breakthroughs in fundamental research and has become an essential instrument in numerous technological applications, including the development of optical frequency combs [3] and hyperspectral microscopy of biological and chemical samples [4]. Ti:sapphire features the widest gain bandwidth of any laser crystal (700 nm - 1100 nm), which enables the generation of ultra-short pulses in mode-locked operation, and widely-tunable lasing in continuous-wave regime, with applications ranging from medical imaging to quantum optics. Due to the short fluorescence lifetime of Ti^{3+} in sapphire, very high output power can be achieved in Ti:sapphire lasers; however, this also means that high pump power is required to achieve population inversion for lasing. Furthermore, there is a large mismatch between the lasing (700 nm - 1100 nm) and pump wavelength (480 nm - 540 nm), which results in the conversion of a substantial fraction of the pump power into heat. As a result, Ti:sapphire lasers require high-power pump lasers and complex temperature management; to date, the Ti:sapphire laser remains an expensive and bulky table-top instrument, preventing its widespread use. Notably, since most applications do not require high laser power, the majority of the laser output is discarded.

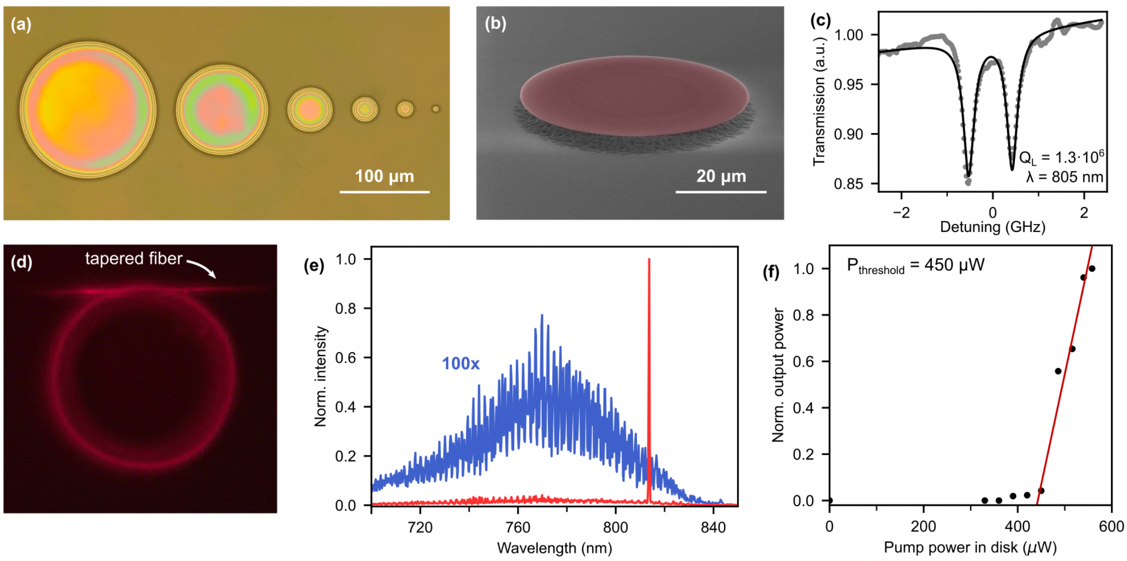

Fig. 1. **Ti:sapphire-on-insulator laser. (a)** Optical microscope image of an array of Ti:sapphire microresonators. **(b)** Colorized scanning electron microscopy image of a 50 μm microdisk. **(c)** Optical quality factors in excess of 1 million are observed within the lasing bandwidth. **(d)** Optical microscope image of the laser below threshold, taken with a long-pass filter to reject the pump laser, showing Ti^{3+} flourescence. **(e)** The amplified spontaneous emission (ASE) spectrum of the device below threshold (blue, multiplied by a factor of 100), and the lasing spectrum. **(f)** The output laser power as a function of the optical pump power.

Device miniaturization through on-chip integration enables compact, low-power, low-cost photonic devices with unprecedented capabilities across a wide range of applications [5]. However, the miniaturization of the Ti:sapphire laser remains elusive. To date, the lowest threshold of 14 mW has been obtained in a millimeter-sized whispering-gallery mode resonator machined out of single-crystal Ti:sapphire [6]. In this work, we demonstrate a thin-film Ti:sapphire microresonator laser with a sub-mW threshold, opening a pathway for the ultimate on-chip miniaturization of Ti:sapphire lasers for industrial and research applications.

Device fabrication

The thin-film titanium:sapphire-on-insulator material platform is produced via an adaptation of the grinding-and-polishing approach described in Ref. [7]. A bulk Ti:sapphire wafer die is first bonded to an undoped sapphire wafer with an SiO_2 interfacial (buried oxide) layer. The bonded Ti:sapphire wafer is then processed in a wafer grinder (DAG810, Disco Corp.), followed by chemical-mechanical polishing (POLI-400L from G&P Tech.), and thinning via reactive-ion etching in BCl_3 plasma (PlasmaTherm Versaline ICP). This results in a ~ 500 nm thick Ti:sapphire film on SiO_2. Microdisk resonators are fabricated via photolithographic pattern transfer through a BCl_3 plasma reactive ion etch. After the photoresist pattern has been transferred into the Ti:sapphire layer, the underlying SiO_2 is undercut in hydroflouric acid. A scanning electron microscope (SEM) image of the completed device is shown in Fig. 1(b).

Device characterization

The sample is mounted on a temperature-controlled stage, and the devices are optically interfaced via a tapered fiber. A scanning laser is used to characterize the resonators in transmssion across the lasing wavelength range. For optical pumping, a 532 nm pump laser is used. The output of the tapered fiber is split between a power meter for resonator mode characterization, and a spectrometer for the characterization of the output spectrum. Optical quality factors in excess of 1 million are observed in transmission (Fig. 1(c)), indicative of low optical losses of the fabricated Ti:sapphire-on-insulator material platform.

Upon excitation of the device with a weak 532 nm pump, Ti^{3+} fluorescence is observed. Fig. 1(d) shows an optical microscope image of the pumped device captured with a color camera. The amplified spontaneous emission (ASE) spectrum of the device below threshold is shown in Fig. 1(e). As the pump laser power is increased, single-mode lasing is observed at a threshold of 450 μW of resonator-coupled pump power (Fig. 1(f)).

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