Low threshold, dual-cavity continuous-wave fiber optical parametric oscillator

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Abstract

A dual-cavity, doubly resonant fiber optical parametric oscillator (FOPO) is proposed. It can reduce the threshold pump power at a ratio of 36% compared with the traditional singly resonant FOPO.

Introduction

Optical parametric oscillators based on $\chi^{(3)}$ nonlinearity of fused silica in optical fiber have long been proposed as a useful means of generating tunable coherent radiation [1, 2]. In the previously reported studies, most of the FOPOs use a singly resonant cavity which allow only the signal to oscillate [3, 4]. Such kind of FOPO usually requires high pump power so that in most cases pulsed pump is used in order to achieve high peak power [5]. Continuous-wave (CW) pump FOPOs are also proposed, in which long length of highly nonlinear fiber (HNLF) and relatively high CW-pump power is used to accumulate enough optical parametric amplifier (OPA) gain [6]. Compared with the small average power in the pulsed pump case, the CW high power pump in the FOPO imposes a big challenge, especially the case where high pump power is required to compensate for the large cavity loss with multiple devices. Such high average pump power would readily damage the optical components, thereby it is a main drawback in the traditional singly resonant CW FOPOs. For an FOPO with the cavity loss of 18.3 dB, the threshold of 1.52 W is required [7]. In this paper, we propose and demonstrate experimentally a dual-cavity doubly resonant continuous-wave FOPO that can reduce the threshold pump power significantly.

In fiber OPA, a strong pump wave creates two sidebands located symmetrically at signal and idler frequencies. So FOPO can emit photons at two different wavelengths that are closely correlated. Here we consider to oscillate signal and idler simultaneously in two separate optical cavities, rather than oscillate only the signal in a single cavity in the traditional FOPO. The proposed configuration and experimental setup is shown in Fig. 1. The gain medium used here is 400-m highly nonlinear dispersion-shifted fiber (HNL-DSF) with the zero dispersion wavelength of 1554 nm. The pump is seeded by an external cavity tunable laser source (TLS) at the wavelength of 1556 nm. To suppress stimulated Brillouin scattering (SBS), the light from the TLS is first phase-modulated with 10-Gb/s pseudo-random bit sequence (PRBS) signal via a phase modulator (PM). Polarization controller PC1 aligns the pump's state of polarization (SOP) with the transmission axis of the PM. The SBS can be suppressed by up to 32 dB using this method. Then the pump is amplified by a two-stage configuration of EDFA, in which the first stage (EDFA1) provides small signal gain to prevent self-saturation by amplified spontaneous emission (ASE). Then it is filtered by a 0.35-nm bandwidth tunable bandpass filter (TBPF1) to reduce ASE noise. After an isolator (ISO1), it is further amplified by the second stage (EDFA2), with a maximum average output power of 33 dBm. Note that the effectiveness of SBS suppression is demonstrated at the beginning of the experiment. Then the pump is coupled into the 400-m HNL-DSF via P-port (transmission band: 1554.89 ~ 1563.89 nm) of a WDM coupler (WDMC1). The high power pump propagates through the HNL-DSF and is then coupled out of the ring cavity through P-port of another similar WDM coupler (WDMC2), while the amplified signal and idler are coupled into the respective ring cavities: firstly through the R-port (reflection bands: 1500 ~ 1551nm, 1567 ~ 1620 nm) of WDMC2 and subsequently are splitted into two paths by a C/L band WDM coupler (WDMC4). In regard to the signal cavity ①, the signal from the C port of WDMC4 is filtered by a 0.35 nm band pass filter (TBPF2) which determines the lasing wavelength. After that a 10/90 optical coupler is used to

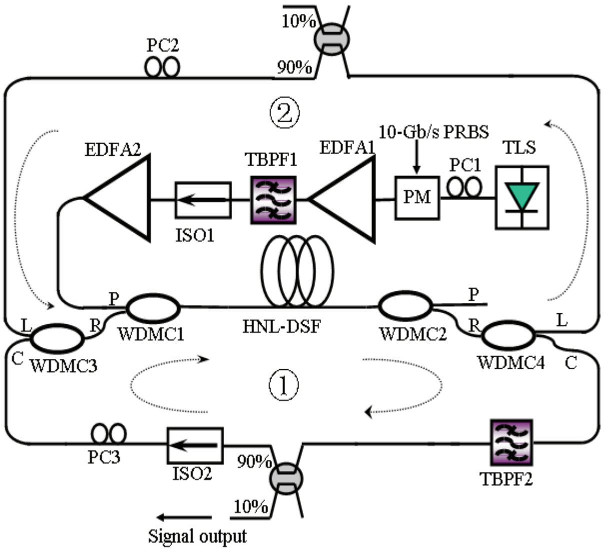

Fig. 1 Schematic diagram of dual-cavity FOPO: ① signal cavity; ② idler cavity.

couple out 10% of signal light to provide the output for the FOPO. The isolator (ISO2) ensures unidirectional operation and prevents oscillation by back reflection. PC3 is used to align the signal's SOP with the pump so as to maximize the signal gain. In regard to the idler cavity ②, the light from L port of the WDMC4 propagates through a 10/90 coupler for monitoring the idler and a polarization controller (PC2) before entering the HNL-DSF via L port of WDMC3.

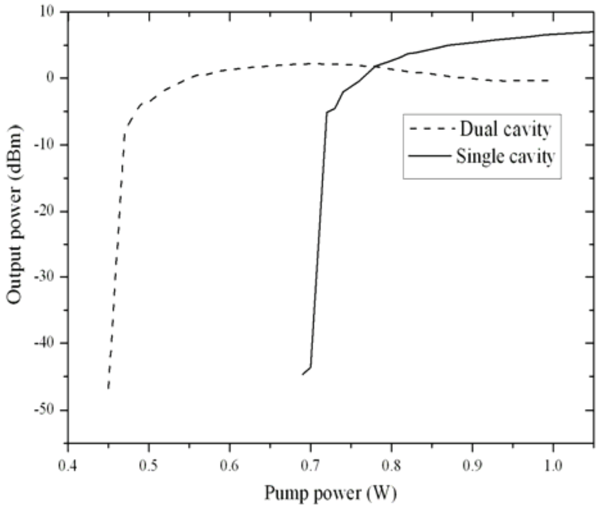

Fig. 2 Output power versus pump power with single and dual cavity configuration.

Fig. 2 shows the relationships between the output power versus the pump power in these two cases. In both cases, when the pump power exceeds the respective threshold, the output power ascends sharply that indicates the beginning of oscillation. In the singly resonant case (① is connected, and ② is disconnected), the threshold pump power is 0.72 W. On the contrary, when the idler cavity is also connected (both ① and ② connected), the threshold pump power is reduced to be only 0.46 W, i.e. dropped by 36%. It indicates that, with signal and idler oscillated simultaneously, the threshold pump power can be reduced greatly compared with singly resonant case. This provides a way to ease the threshold requirement of CW pumped FOPO. In the singly resonant case, the output power rises monotonously with the pump power before the gain is saturated. The output power increases to be 7.7 dBm when the pump power is 1.13 W. Whereas, in the doubly resonant case, the output power rises monotonously with pump as the pump power is lower than 0.7 W. If the pump power is increased further, the output power will drop. And the output power of the doubly resonant FOPO is smaller than that in the singly resonant case under the same pump power. It can be explained as follows: there is no mode restriction device in the idler cavity in the dual-cavity configuration. When the pump power is high enough, the idler demonstrates a broad band spectrum as wide as the gain bandwidth of the OPA and this depletes the pump significantly in the doubly resonant case. So instead, the output power of FOPO in the doubly resonant case decreases on the contrary when the pump power exceeds 0.7 W.

Fig. 3 shows the measured optical spectrum of the output of the dual-cavity FOPO from the optical spectrum analyzer (OSA) with a resolution of 0.5 nm when the pump power is 0.55W. The oscillating wavelength is 1542.48 nm. The side mode suppression ratio (SMSR) is more than 55 dB.

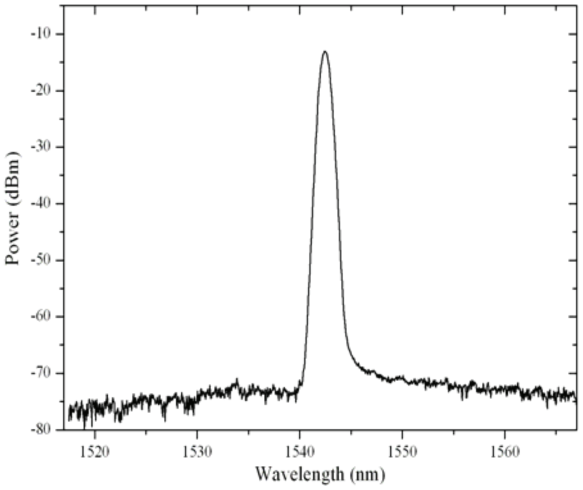

Fig. 3 optical spectrum of the output of the dual-cavity FOPO.

Conclusions

In conclusion, we have presented a dual-cavity fiber OPO. The FOPO is fundamentally structured by resonating independently the nondegenerate signal and idler frequencies in two separate optical cavities. The proposed dual-cavity FOPO can lower threshold pump power by 36% compared with the traditional singly resonant CW FOPO.

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