

Dissipative Kerr solitons in a warm atomic vapor system

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Abstract: Dissipative Kerr solitons generated by four-wave mixing in hot rubidium atoms within a phase conjugate resonator are presented. The solitons are tunable with pump detuning and laser power and exhibit Turing rolls and dark-soliton formation.

1. Introduction

Dissipative Kerr solitons (DKSs) [1] are self-localized photonic structures resulting from the double balance of dispersion by nonlinearity and loss by parametric gain. Mathematically, DKSs represent self-enforcing stationary localized solutions of a damped, driven, and detuned nonlinear Schrödinger equation, which was originally used to describe spatial self-organization phenomena. DKSs in an atomic system provide an experimental platform to study dissipative Kerr soliton physics, and DKSs generally have practical applications in coherent comb spectra and coherent communications. Recently DKSs have been demonstrated with microresonator systems constructed with solid-state material such as silica [1, 2].

Compared with solid-state material, atoms in the gas phase have spectrally narrow transitions and long coherence times. Light-atom interactions with resonant enhancement have historically attracted interest for their strong and tunable nonlinearity and dispersion, such as slow, fast, and stored light [3]. In the quantum regime, atomic vapors have been explored for quantum light sources [4] and quantum metrology systems.

Here we show DKSs from four-wave mixing (FWM) in hot rubidium atoms within a phase conjugate resonator. The resonator consists of a rubidium vapor cell (~12.5 mm), a single-mode optical fiber (~107 m), and a several-meter-long free space between the vapor cell and the fiber. The pump can be easily tuned from the atomic resonance which tailors the dispersion. A second difference from microresonator systems is that the pump light does not circulate within the resonator. Thus, the resonator does not suffer from thermal issues. Last, we have utilized the phase conjugate resonator where the time-reversal property compensates various phase disturbances so that coherent optical combs and DKSs are stably observed without any active locking; cavity modes are tied to the pump frequency. In the experiment, we found that the DKSs are tunable with pump detuning (from atomic resonance) and laser power, and exhibit abundant DKS phenomena such as Turing rolls and dark-soliton formation [1, 2].

2. Experimental setup and results: dissipative Kerr solitons

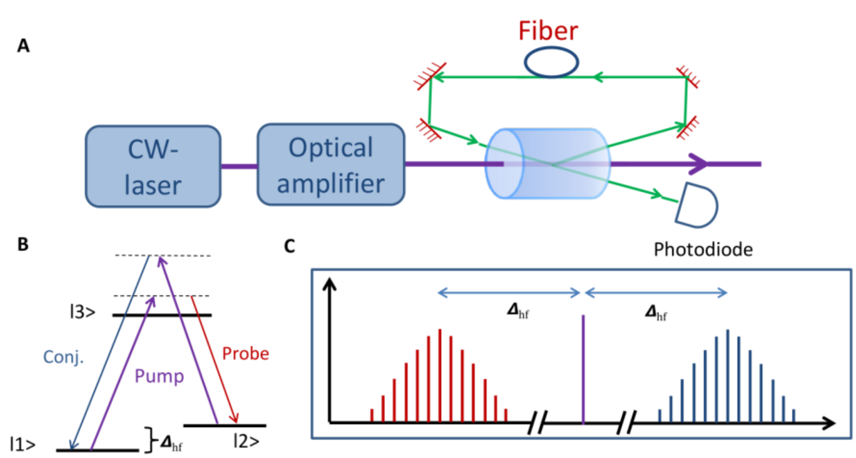

Fig.1. (A) Four-wave mixing process in a double-lambda energy level scheme, (B) a schematic diagram of the experimental setup, and (C) a schematic showing of the output spectra.

The process is based on a co-propagating FWM process in hot rubidium vapor. When a single frequency pump laser is injected into the double-lambda scheme, the probe and the conjugate photons will be spontaneously emitted, collected, and sent back to the process via a ring cavity. The feedback direction is through a glancing angle, not the normal cavity angle. Probe and conjugate photons will be converted to one other, back and forth on reflection. The process is phase coherent due to the phase conjugation without any active locking. When the gain bandwidth of the FWM is larger than the mode spacing of the ring cavity (which can be tuned easily by the fiber length), the phase-coherent optical frequency comb will be generated [5].

Via careful tuning of the double balance of dispersion by nonlinearity and loss by parametric gain through the pump frequency or the pump power, abundant DKS phenomena have been observed. For example, Fig.2 presents the DKSs' dependence on the pump power. Compared with the primary period of 1084ns, there are multiple Turing rolls with high pump power. The roll number decreases as the pump power decreases. Eventually, the dark-pulsing formation appears. As quantum-correlated light sources are readily constructed with this same four-wave mixing process in hot rubidium atoms [3,4], the most interesting thing in the future is to explore the quantum properties of this source.

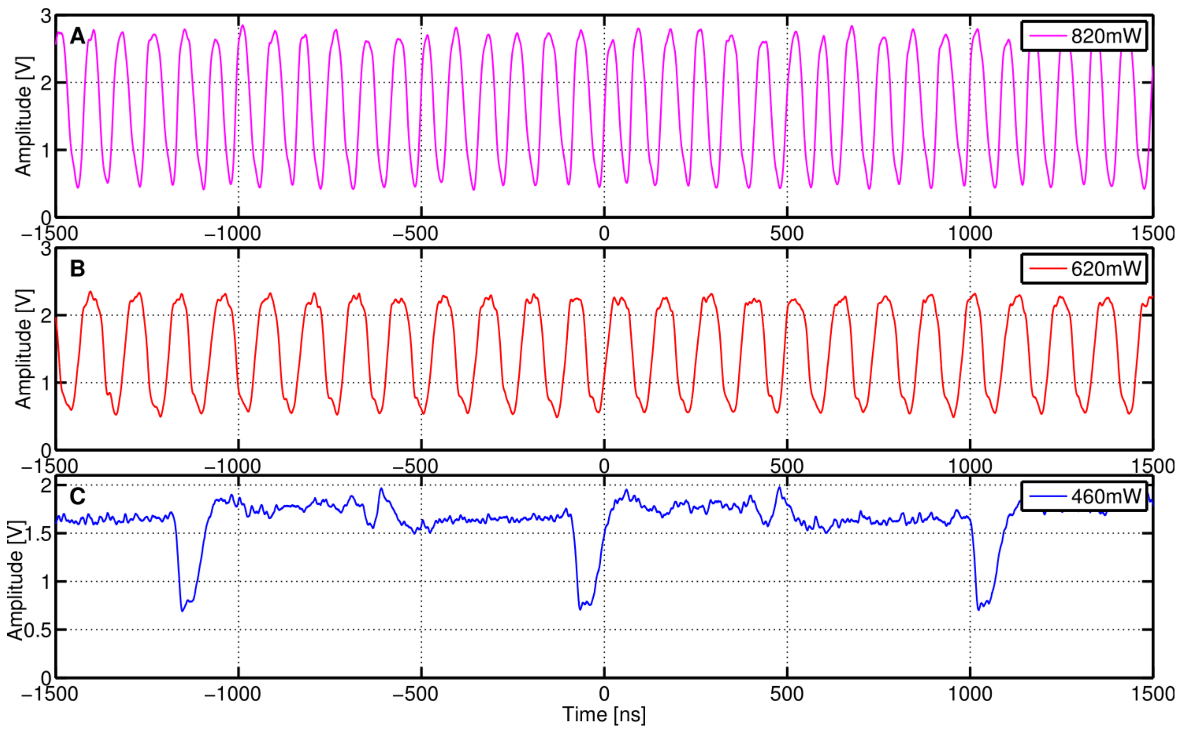

Fig. 2. Dissipative Kerr solitons are dependent on the laser power as a control parameter. The primary period is 1084 ns determined by the cavity length 2nL/c, where n is the effective refractive index, L is the length of the resonator and c is the speed of light. (A) When the pump is 820mW, there are multiple pulses (with 12 Turing rolls). (B) As the pump power decreases, the roll number also decreases. For example, 620mW pump power yields 6 Turing rolls. (C) With an even lower pump power (460mW), the dark-soliton formation appears.

3. References

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