강한 이색광과 광주파수 빗으로 구동된 3준위 원자를 이용한 광주파수 빗의 고차 조화파 발생

High-harmonic generation of an optical frequency comb by using three-level atoms driven by an optical frequency comb and a strong bi-chromatic field

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We consider a possible way to extend the spectral region and to amplify weak intensity of an optical frequency comb by using a two-photon coherence in a three-level atoms. We calculate numerically the solutions of density matrix equations for the case for an effective two-level system corresponding to a three-level Λ-scheme with far-off resonant detunings from the upper state. In our theoretical model the fields consist of two strong bi-chromatic fields that connect the three-level Λ-scheme with a small Raman detuning. In addition to this a phase coherent optical frequency comb, which we assumed to be phase coherent to the two bi-chromatic fields and has a repetition rate in an integer fraction of the frequency separation of the two-ground states, is co-propagating with the two bi-chromatic fields. In the numerical calculation, we used the Rabi frequencies of the bi-chromatic and optical frequency combs as 5 ~ 50 Γ and 0.01 Γ ~ 0.1 Γ, respectively, where Γ is the decay rate of the excited state and the spectrum of the each optical frequency comb has 100 ~ 1000 longitudinal modes. We investigate the physical origin of the broadening and amplification of the weak optical frequency comb by considering a nonlinear interference effect that is induced in the polarization spectrum of the medium when a strong bi-chromatic fields and a poly-chromatic weak field couple the two effective atomic states. The resulting superposition state of the atoms irradiate at the new frequencies, especially to the high-harmonic frequencies of the ground-state frequency separation with a series of amplified optical frequency comb at their wings. We expect our numerical study may help to make a phase coherent UV or XUV combs by using dressed three level atoms.

We understand from our previous researches for the two- and three-level atoms in a poly-harmonic field excitation(1)-(3) that the enhancement of the intensities of the comb components takes place because the atomic system exhibiting a strong nonlinearity driven by a strong bi-chromatic field, since there are high orders of beat frequency due to Raman transitions (effective

2-level system) so that there are generation of equidistant harmonic field at each order of the beat frequency. Note that efficient broadening and amplification of an optical frequency comb take place when the comb frequency (repetition rate, δ) is an integer fraction of the beat (modulation frequency Ω) frequency like $m\delta = \Omega$. In this study, by changing the parameters of atoms and fields, we could be able to adjust not only the generated spectrum of the optical frequency comb, but also the intensity of the optical frequency comb components in a broad range of field parameters. Because detuning of the laser frequencies from the upper level is large (~ 100 Γ) and frequency difference between laser frequency is near two-photon Raman resonance the strong efficient two-photon transition could be generated. Generation of high harmonics of the modulation frequency Ω is experimentally and theoretically studied previously(4),(5). Recently it was proposed to use a optical frequency comb whose spectrum covers the frequency difference between lower levels for the generation of high harmonics of the Raman frequencies(5). A typical example of the spectrum of resonance fluorescence on the high harmonics of beat frequency is shown on Fig.1.

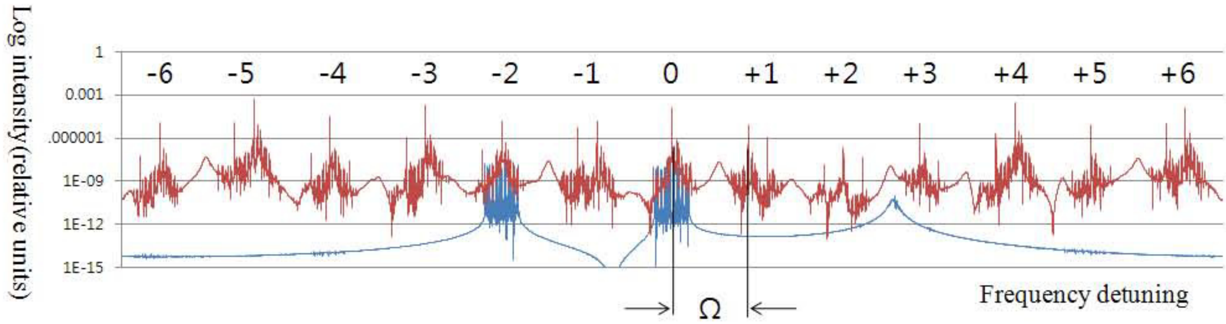

Fig. 1. A spectral broadening in few times and amplification in few orders can be seen compared to the original weak optical frequency comb when a strong bi-chromatic field is turn on (upper curve). The lower curve is the case when a strong bi-harmonic field is absent.

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