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Coupling Length Phase Matching in Parallel Waveguides

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Abstract: We show that phase-matching for frequency conversion is possible in a system consisting of two parallel waveguides without any spatial modulation of linear or nonlinear optical properties, both for second and for third-order effects.

OCIS codes: (190.4223) Nonlinear wave mixing; (230.7370) Waveguides.

1. Third-order interaction of three waves in parallel waveguides

The coupling constants between closely spaced parallel waveguides can play the role of a missing wavevector for phase-matched nonlinear optical interaction of waves of different wavelength, with the phase matching condition dependent on the coupling length. This Coupling Length Phase Matching (CLPM) process can be used to obtain quasi-phase phase matching in the absence of any modulation of the linear or nonlinear optical properties of the material. Using CLPM it therefore becomes possible to realize various phase matched second and third-order frequency conversion processes in parallel waveguides [1].

A general framework for CLPM has been developed in Ref. 1. Fig. 1 is a cartoon of the basic principle of the technique in two identical, parallel waveguides (a) and (b). The qualitative depiction in this figure corresponds to the case of sum-frequency generation, $\omega_3 = \omega_1 + \omega_2$ but the general principle applies to all possible frequency conversion processes based on second and third-order nonlinearities. The pump beams at frequency ω_1 and ω_2 are injected in waveguide a. The evanescent coupling between the two waveguides causes the power of the pump waves to oscillate between the two waveguides (schematically represented in this sketch by the two lines meandering between the two waveguides). Under the appropriate CLPM condition it is possible to arrange for the signal wave at frequency ω_3 that is created by nonlinear optical interaction of the two pump waves to grow constructively with propagation length, in both waveguides.

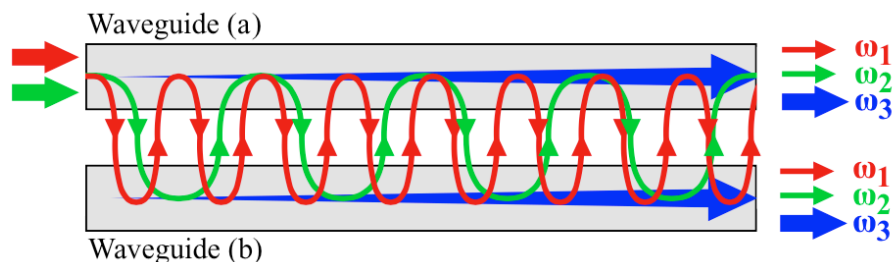


Fig. 1. Basic principle of CLPM in parallel waveguides. The qualitative depiction in this figure corresponds to the case of sum-frequency generation, $\omega_3 = \omega_1 + \omega_2$, but CLPM conditions can be found for any second-order or third-order frequency conversion process

The coupling constants between waveguides such as those schematically represented in Fig. 1 play the role of “coupling wave vectors” that can compensate any mismatch between the sum of the wave vectors of the fundamental waves and that of the generated wave. We systematically analyzed CLPM in two coupled parallel waveguides in the absence of any modulation of linear or nonlinear optical properties, and we developed a general framework that can be used to obtain a varied amount of phase matching conditions. As an example, a large set of CLPM conditions can be derived analytically for both second-order and third-order frequency conversion processes. Examples are sum-frequency generation, second harmonic generation, and difference-frequency generation for the second order processes, and frequency downconversion via third-order quasi-degenerate four-wave mixing [1]. CLPM for third harmonic generation can also be obtained using the same methods [2].

2. Overview of potential applications of CLPM

The second-order CLPM processes seem particularly attractive for frequency conversion applications in isotropic materials that possess large optical nonlinearities, but for which birefringent phase matching cannot be applied and conventional quasi-phase-matching methods are difficult. An example is gallium arsenide (GaAs), which has a large nonlinearity and a wide transparency range, making it very attractive for mid-IR coherent sources. While relevant efforts to engineer quasi-phase-matching in GaAs have been ongoing, the use of CLPM processes represents a valid alternative that can be easily realized by simply creating two parallel waveguides using well-established methods. CLPM would then enable, e.g., difference-frequency generation between wavelengths of 1.5 and 2.1 μm to deliver radiation near 5.25 μm , while a source at $\sim 10 \mu\text{m}$ could be built by difference-frequency generation between 2.5 μm and 2 μm . Similarly, CLPM *third-order* process like quasi-degenerate four wave mixing could be used in amorphous materials like dual core glass fibers to combine two near-infrared laser sources for obtaining longer wavelength radiation. As an example, mixing the outputs of a 1550-nm fiber laser and of a 1064-nm Nd:YAG laser would deliver radiation near 2.85 μm , or combining the output of a 960-nm laser diode that pumps an erbium fiber laser with the output of the fiber laser itself would produce a wavelength near 4 μm .

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