Supplemental Document

Optics Letters

Optical frequency generation using fiber Bragg grating filters for applications in portable quantum sensing: supplement

CALUM D. MACRAE,* KAI BONGS, AND MICHAEL HOLYNSKI

University of Birmingham, School of Physics and Astronomy, Edgbaston, Birmingham, B15 2TT, UK
*Corresponding author: calumdonaldmacrae@gmail.com

Supplement DOI: https://doi.org/10.6084/m9.figshare.13578338

Parent Article DOI: https://doi.org/10.1364/OL.415963

Optical frequency generation using fiber Bragg grating filters for applications in portable atom interferometry: supplemental document

1. GENERATING MULTIPLE OPTICAL FREQUENCIES

Both laser cooling and Raman excitation require two optical frequencies to be generated simultaneously. When these are generated in a single, frequency-doubled laser beam, the process is subject to sum frequency generation. For a laser beam with frequencies, Ω_1 and Ω_2, with electric field amplitudes, E_1 and E_2, the electric field strength can be described as[1]:

$$E(t) = E_1 e^{-i\Omega_1 t} + E_2 e^{-i\Omega_2 t} + c.c. \tag{S1}$$

When this is incident on a nonlinear crystal with a second-order electric susceptibility, $\chi^{(2)}$, a nonlinear polarization is created[1]:

$$P^{(2)}(t) = \epsilon_0 \chi^{(2)} E(t)^2 \tag{S2}$$

where ϵ_0 is the permittivity of freespace. This can be shown to generate light at frequencies $2\Omega_1$, $2\Omega_2$, $\Omega_1 + \Omega_2$ and $\Omega_1 - \Omega_2$[1]. Assuming only two frequencies, Ω_A and Ω_B, are desired at the laser output, and the desired amplitude of $\Omega_A > \Omega_B$, spectral purity is maximized by setting $\Omega_A = 2\Omega_1$ and $\Omega_B = \Omega_1 + \Omega_2$. Figure S1 shows spectra before and after the nonlinear crystal.

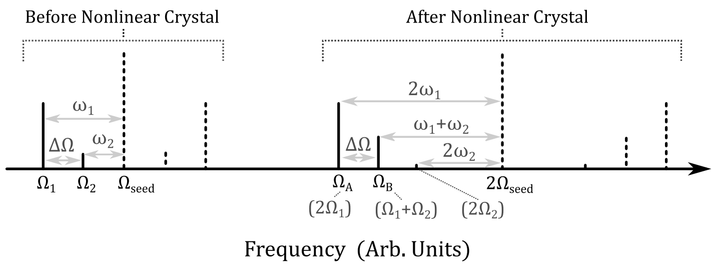

Fig. S1. Optical spectra before and after the nonlinear crystal. Black and dotted lines denote frequencies reflected and transmitted by the fiber Bragg gratings respectively.

For frequency sidebands at RF frequencies, ω_1 and ω_2, which are applied with an electro-optic modulator at 1560 nm, the optical spectrum after the nonlinear crystal will contain the desired frequencies at $\Omega_A = 2\Omega_{seed} - 2\omega_1$ and $\Omega_B = 2\Omega_{seed} - (\omega_1 + \omega_2)$, where Ω_{seed} is the optical frequency of the seed laser. Notably, the difference in frequencies, $\Delta\Omega$, is the same before and after the nonlinear crystal, i.e. $\Omega_A - \Omega_B = \Omega_1 - \Omega_2$. Ω_{seed} is locked at $\frac{\Omega_{lock}+\omega_{offset}}{2}$, where Ω_{lock} is the frequency of the atomic reference and ω_{offset} is the lock offset frequency.

During laser cooling, the cooling optical frequency is swept whilst the repumper frequency remains fixed. Because the amplitude of the repumper frequency is less than that of the cooling, the cooling and repumper frequencies are generated at Ω_A and Ω_B respectively. Because Ω_B is dependent on both ω_1 and ω_2, to maintain the repumper at a fixed optical frequency, ω_2 must be decreased when ω_1 is increased. This was achieved experimentally by generating ω_1 and ω_2 using RF mixers with a common intermediate frequency, as shown in Figure 3.

REFERENCES

1. R. Boyd, *Nonlinear Optics* (Academic Press, 2008).