Design and Performance of a Narrowband VCO at 282 THz

A single-mode optical signal source whose frequency can be voltage-controlled has been developed. We describe its design and performance.

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The development of extensive fiber-optic networks has increased the spectral range of communication carriers to frequencies in excess of 200 THz (wavelength = 1500 nm). Test instruments designed for use with such systems and their components often require signal sources with good frequency control and spectral purity.

A great deal of progress has been made in the development of broadly tunable optical sources with spectral linewidths less than 100 kHz. This has led to the development of commercial instruments such as the HP 8167A and HP 8168A tunable laser sources,[1] which use a semiconductor laser chip for amplification and the combination of a grating and an etalon for frequency control and tuning. In this article we describe an alternate approach to tunable laser sources that has high spectral purity and very rapid tuning.[2]

Noise characteristics of the electrically excited semiconductor amplifier place limits on the spectral purity of the signal source. The noise characteristics of the amplifying medium can be improved by using an optically pumped crystal and that is the approach taken in the design of the oscillator described in this paper. However, to achieve substantially improved spectral purity we sacrifice broad tunability. Therefore, the resulting source will be complementary to semiconductor laser sources, making it possible to address applications that require very high spectral purity within a narrow range of frequencies.

Laser Description

A laser is an oscillator operating at optical frequencies. Like all oscillators, it consists of an amplifier and a means for applying positive feedback to that amplifier. The tuning range of an oscillator is the set of frequencies for which the gain of the amplifier is large enough to compensate for losses in the system. To ensure single-frequency oscillation, one must design the feedback mechanism to allow only one frequency within the amplifier bandwidth.

In an optical oscillator, feedback is supplied by reflectors that form a resonant cavity containing the amplifier. The spacing of the reflectors determines the axial resonant modes of the cavity. Each cavity mode corresponds to a frequency for which an integral number of half wavelengths of oscillation will just fit within the cavity. Since typical laser cavities have lengths much greater than the optical wavelengths, a large number of optical modes can be defined by a particular cavity configuration. The frequency spacing $\Delta\nu$ of these modes is inversely proportional to the cavity reflector separation:

$$\Delta\nu = c/2nl,$$

where $\Delta\nu$ is the frequency spacing, c is the speed of light, n is the index of refraction of the material in the cavity, and l is the length of the cavity.

The amplifier in the system we have built is a crystal of yttrium orthovanadate, YVO_4, doped with 1.5% neodymium. The Nd atoms displace some of the Y atoms in the crystal structure and provide Nd^{3+} ions that have a set of energy levels that can be optically excited by the output of a semiconductor laser operating at 808 nm. The excited Nd ions can then emit radiation over a frequency range of about 240 GHz centered at 282 THz (1064 nm). This emission can occur spontaneously or can be stimulated by the presence of ambient 282-THz radiation, amplifying it.

Since the amplifier bandwidth is much narrower than the 9-THz bandwidth of the semiconductor chips used in the HP 8167/8A laser sources, we can use a relatively simple strategy to ensure that this laser will operate at a single frequency. If the cavity is made short enough so that its frequency spacing is greater than the emission frequency range of the Nd^{3+} ions then the condition for single-mode operation will certainly be satisfied. The index of refraction of the $Nd{:}YVO_4$ is about 2.1, so the cavity must be less than about 0.3 mm long to ensure single-frequency operation. For a cavity longer than 0.3 mm, one can still obtain single-frequency operation by controlling the length so that one of the cavity modes has a frequency near the peak frequency of the amplifier gain curve. However, as the cavity length is increased and the mode spacing decreases, it becomes more likely that a second mode will have enough gain to oscillate. This implies that the cavity must be as short as practical, but need be no shorter than 0.3 mm.

The requirement for a short cavity drove the choice of laser crystal. Of all Nd-doped crystals available in reasonable commercial quantities, $Nd{:}YVO_4$ is an ideal laser material for this application because its Nd ions exhibit a high probability for absorption of 808-nm light from commercially available diode lasers and very efficient reemission of light at 1064 nm. This means that a small amount of the material can have enough gain to reach the threshold for laser action at modest levels of optical pumping power. In addition, the emitted radiation is preferentially polarized along one of the crystal

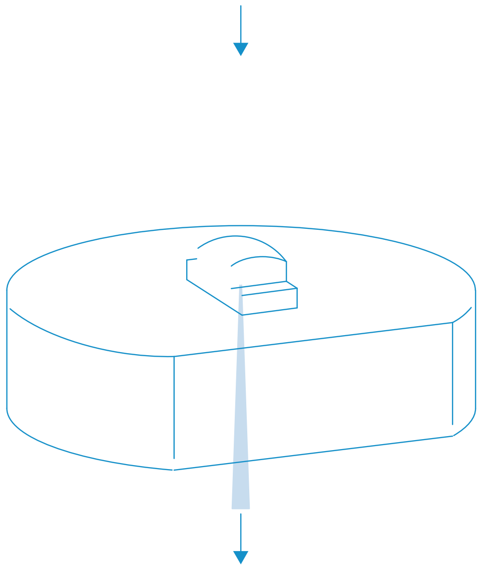

Fig. 1. Design of the narrowband laser operating at 282 THz (1064 nm).