Bragg Range Michelson Mode Selector (BRaMMS)

UniKLasers, headed by Prof Fedor Karpushko, has developed a patent protected method of producing natural single frequency laser emission, which has a number of advantages over alternative methods. Namely;

- Extremely narrow line-widths that can be below 100 kHz.
- Stability that relies only on temperature control to within a few degrees centigrade.
- Tuning control of the output by up to 50 GHz or lock it to an external reference.

How it works

To understand how this technology works to deliver the exceptional beam characteristics, let us consider the basic design of a DPSS laser.

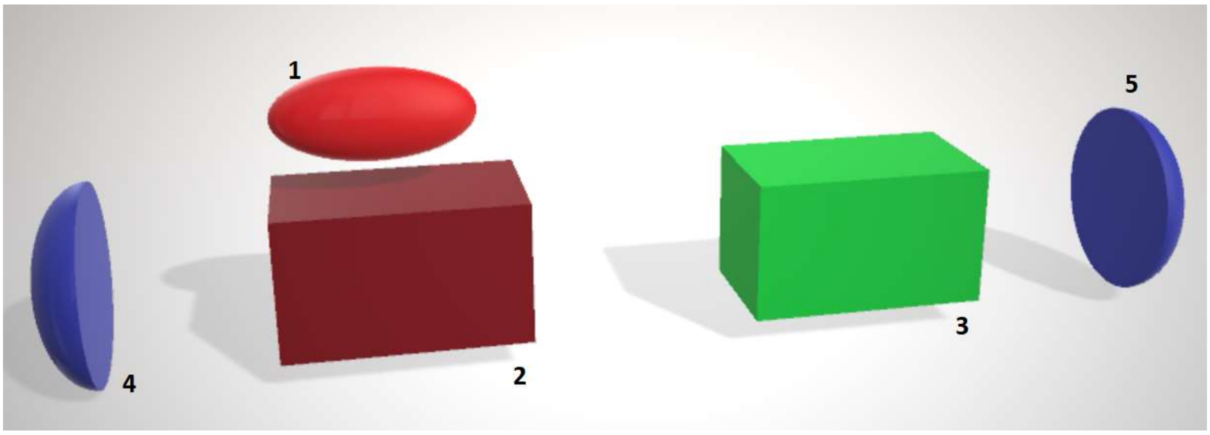

Fig 1. Basic layout of a DPSS laser

A DPSS laser consists of a set of crystals and optics that are common to many designs. (Fig 1.)

1. Source of excitation energy. Often diodes, but sometimes an electrical current.
2. A rare earth doped crystal (gain media) that through the stimulated emission creates the initial coherent light.
3. A second harmonic crystal (such as BBO), that converts the fundamental light from the gain media into higher frequency light. This crystal is not needed if the fundamental frequency is the required output.
4. An end cavity high reflectivity mirror, that directs the photon energy back into the cavity.
5. An end cavity mirror that allows a small percentage (~5%) of the photon energy to escape the cavity, and become the laser beam.
   (There are also other optics to control, direct and shape the beam, but these are not shown above)

There is a wide range of gain media that offer different fundamental outputs: e.g.:

Media	**Fundamental wavelength generated (nm)**
Nd:YAG	1064
Nd:YLF	1047
Yb:YAG	1030

However due to the different energy states available, each of these gain media also emits at other wavelengths such as Nd:YAG at 1320 nm. Emission therefore is said to be multimode since each of these wavelengths beats against each other to create a bandwidth of emission rather than a single frequency.

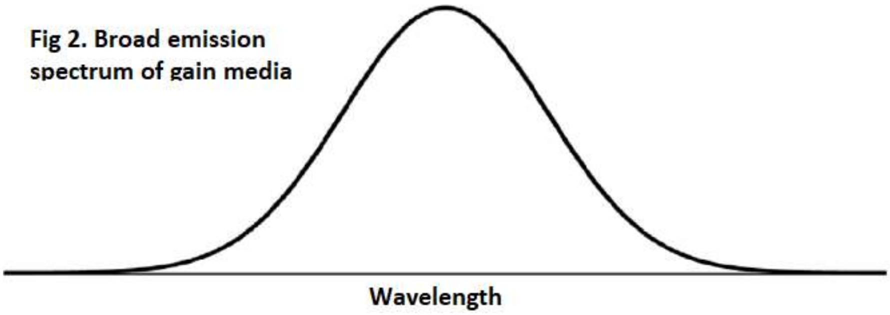

Fig 2. Broad emission spectrum of gain media

The gain output might therefore be considered to look like this:

Since light is a wave and its persistence in the cavity is reliant on reflection by the two end cavity mirrors, only discreet wavelengths of emission can be supported. Specifically, the cavity length must be a multiple of (wavelength/2).

A cavity scan of possible wavelengths would therefore look like this:

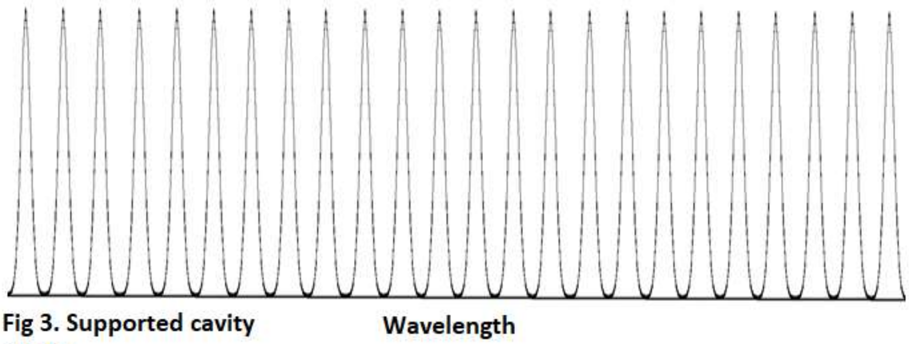

Fig 3. Supported cavity modes

Combining these two images, the emission profile of a laser would then look like this:

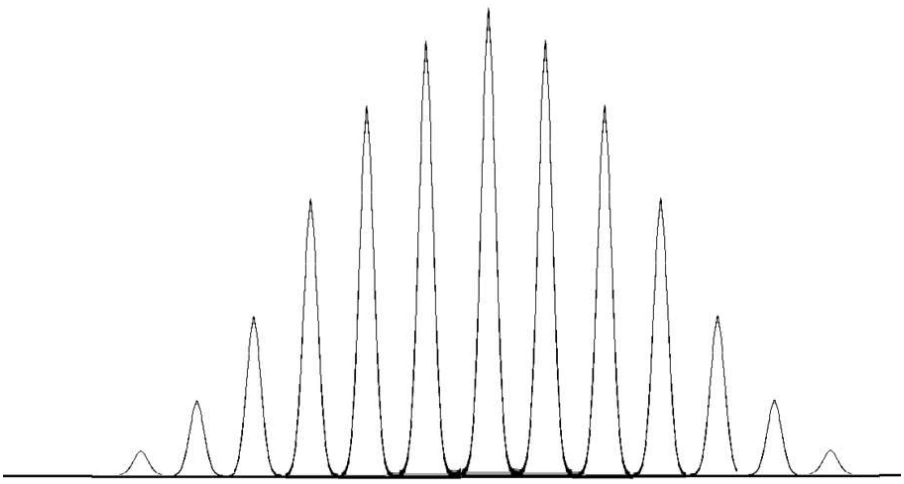

Fig 4. Resultant output from Multimode laser

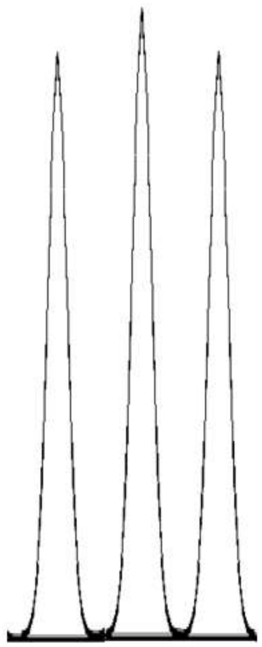

Fig.5 Actual output (not showing beating lines)

In practice, frequencies that are not highly supported will naturally be quenched and will not lase. Leaving emission under these circumstances looking like this, with discreet wavelengths within a range. Not shown here are the additional frequencies caused by interaction and beating between these fundamentals. Typically, a multi-mode laser will have around 20-30 modes i.e. discreet frequencies in its emission profile. As the energy in each mode can switch to an adjacent mode, the optical noise of this output can be high unless further methods are used to filter modes or otherwise ensure the noise levels are lowered.

For many applications, the target of the laser is not sensitive to these mixtures of wavelengths or noise fluctuations for example low resolution Raman, fluorescence microscopy, light shows, etc, but for many applications, the single frequency nature is either an advantage or an absolute requirement to obtain the required results. Holography, interferometry, LiDAR, Brillouin scattering atom cooling, atom spectroscopy for optical clocks, to name a few.

For these applications, the broadband light needs to be narrowed or eliminated to simply a single mode. It is the creation of single mode output that UniKLasers has developed the BRaMMS technology.

BRaMMS technology

EU Patent No 2424051 and US No 8,498,316 B2, describe the BRaMMS method as invented by Prof Karpushko, and relies on the addition of a beam splitter and a volume Bragg grating. This beam splitter (1), Bragg grating (2) and end cavity is arranged to form a Michelson interferometer, with the spectrum discriminatory feature of a Michelson interferometer setup within a spectral range preselected by Volume Bragg Grating (VBG). Fig 6.

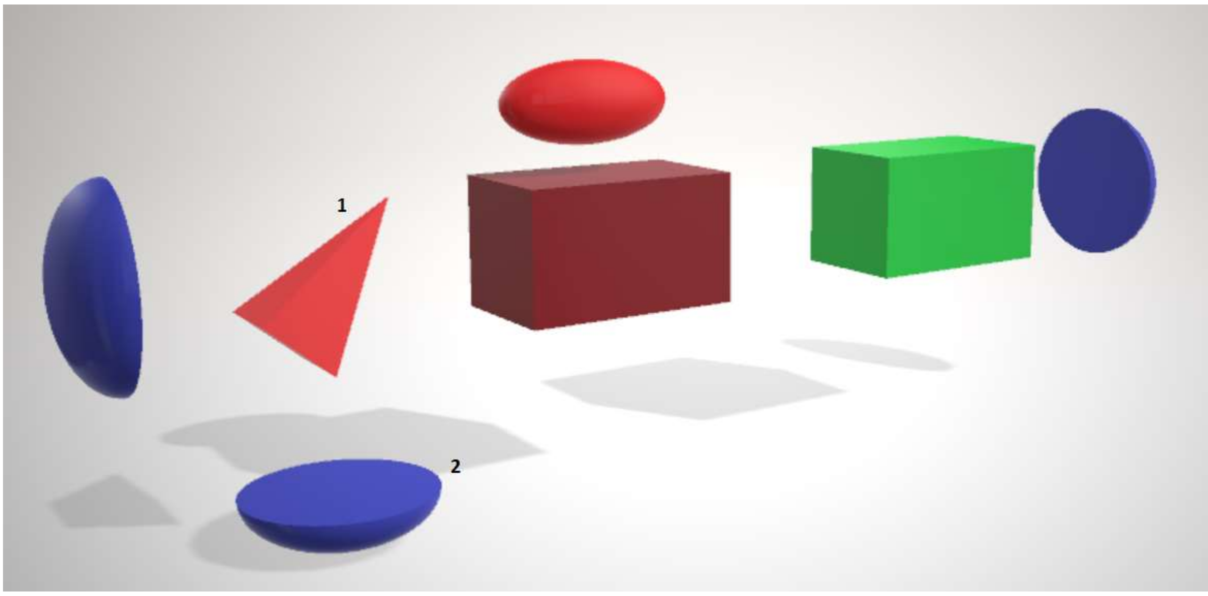

Fig 6. BRaMMS layout with addition of beam splitter and VBG.

The beam path looks like this.

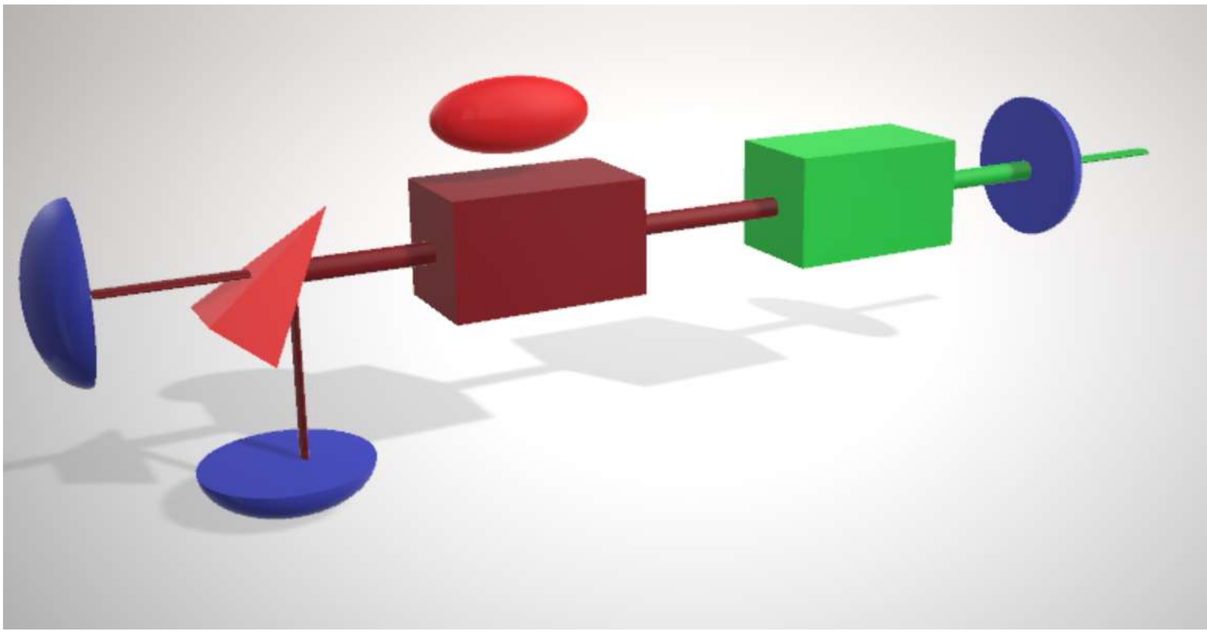
Fig 7. Beam paths in BRaMMS laser

Since the isolation and selection of the single frequency is managed by the VBG/Michelson, the only source of variation is the length of the cavity, which changes the cavity scan shown in Fig 3. It is therefore critical for optimum operation that the position of the end cavity mirrors and the temperature of the cavity are monitored and controlled. All critical components are maintained at factory set temperatures and controlled by peltier cooling to minimise any variation caused by external temperature fluctuations. Absolute stability is easily achieved by a final addition to the laser design. A small amount of leakage is allowed from the Michelson, falling onto a split diode, part of a feedback loop to the PZT mounted end mirrors.

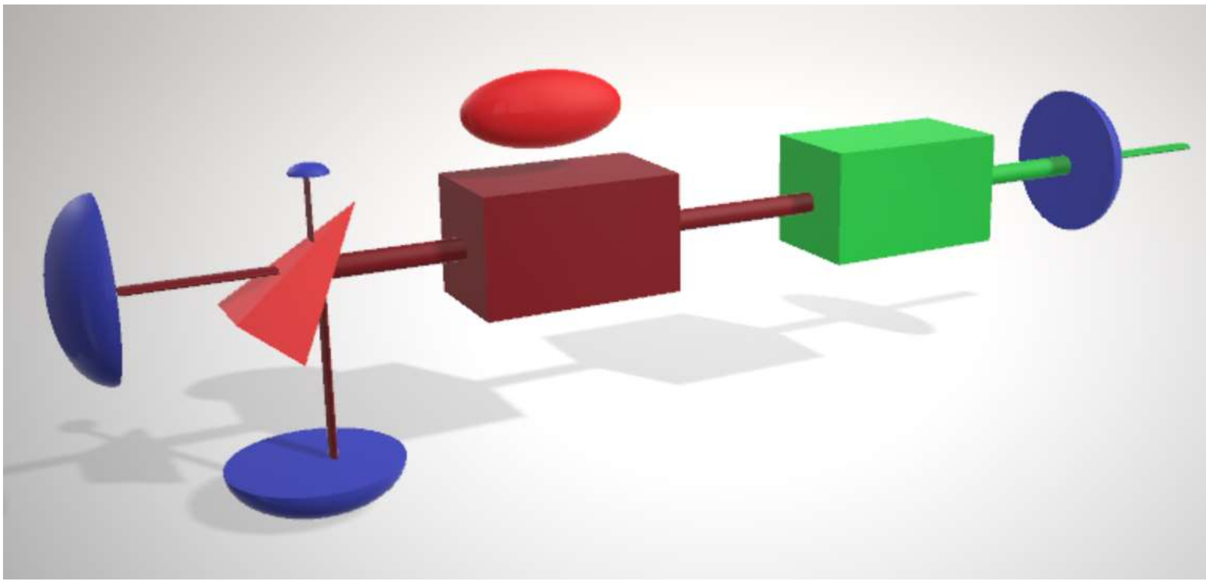

Fig 8. Last addition of the split diode

<u>So what are the outcomes?</u>

The use of the Michelson arrangement ensures absolute single frequency of operation, with standard linewidths below 500 kHz, giving coherence lengths well in excess of 100m and free-running frequency drift as low as 1pm over 4 hours and an ambient temperature drift of 5°C(see Fig 9 and 10). This stability can be further increased by the use of active heat sinks that maintain the baseplate temperature during laser operation.

Some applications such as atom cooling or acting as the clock laser in an optical clock demand higher levels of stability and even narrower linewidths. This can be achieved with the BRaMMS lasers in the new Quantum QT range of lasers designed specifically for this purpose. The feedback loop for the end cavity mirrors is handed over to external electronics allowing a simple "tilt-locking" technique to adjust the pzt controlled mirrors, without application of modulation on the output beam.
The result is line narrowing to below 100 kHz, with an eventual target of a few tens of kHz, and output frequency stability that is limited by the external reference.

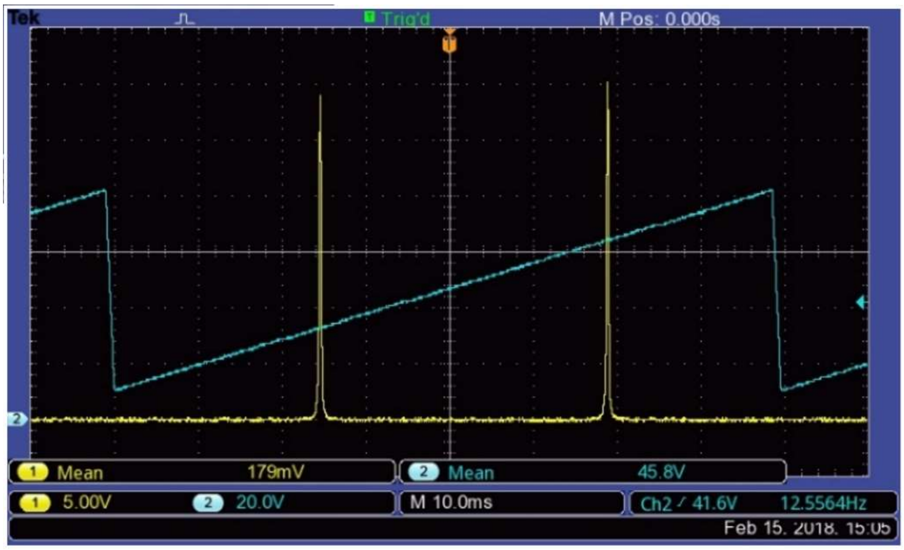

Fig 9. Single frequency linewidth < 500 kHz

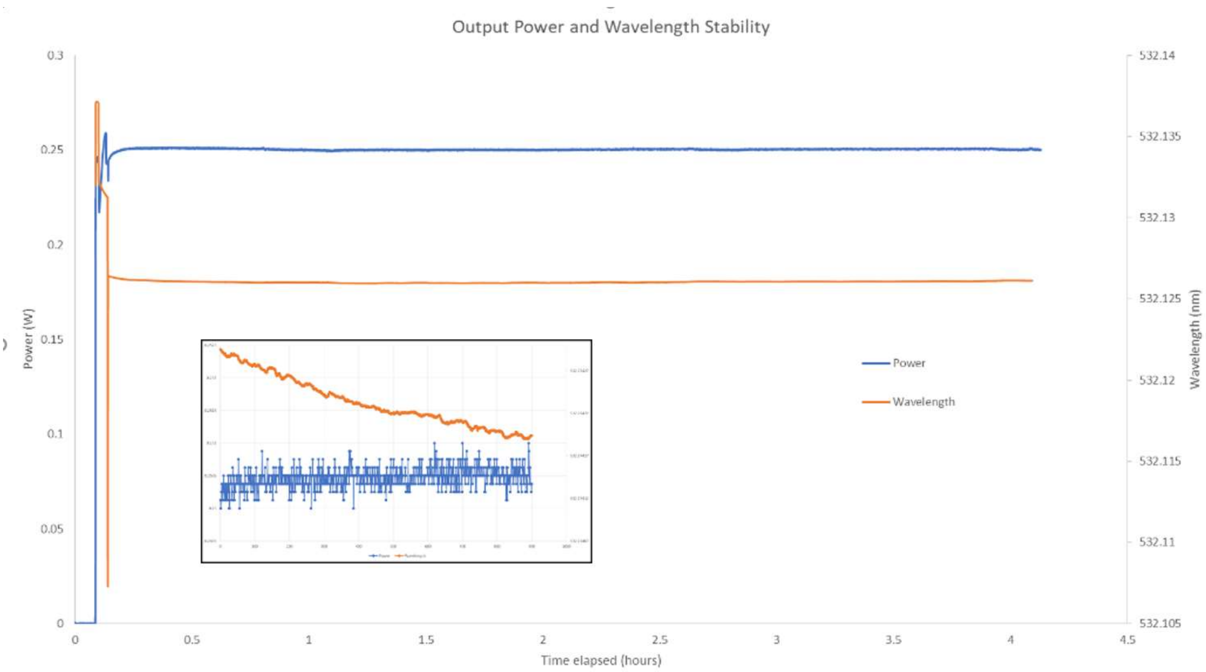

Fig 10. Data taken with a 250 mw Solo-640 on an optical bench over 4 hours.
Inset: A 20 minutes expansion showing 0.1pm wavelength and 1 mW power drift (P-to-P)