27: Iodine Stabilized HeNe Lasers

Unlike the more common HeNe stabilized lasers like those that lock to some intrinsic feature of the lasing process like the neon gain curve, an Iodine Stabilized HeNe Laser (ISHL) uses a external gas cell containing iodine vapor, so that a line in the iodine absorption spectrum is used as the reference wavelength. In principle, this provides an improvement in long term wavelength accuracy of 1 to 2 orders of magnitude – down to 0.1 parts per billion, corresponding to a few 10s of kHz – or better.

An ISHL operating on the common red (633 nm) wavelength typically consists of a HeNe laser tube with one or two Brewster windows, a gas cell containing iodine at low pressure, and at least one external mirror on a PieZo Transducer (PZT) for fine cavity length control. With this arrangement, the iodine cell is installed *inside* the laser cavity to benefit from the high intra-cavity circulating power as the absorption sensitivity in the vicinity of 633 nm is very low. The sensitivity is further boosted since it is a function of the difference between the gain and cavity losses. However, when operating on the green (543.5 nm) wavelength, the cell can be external despite the lower power generally achievable with green, because the sensitivity is higher. But there may be ways to boost the sensitivity using an internal mirror HeNe laser tube operating single longitudinal mode with 2 mW or more output power.

The basic principles of operation for an ISHL are rather straightforward: The iodine (or actually I_2) has a very complex absorption spectra with hundreds of absorption lines. A very small portion of it is shown in: Iodine Absorption Spectrum Near 532 nm. By dithering the laser cavity length via a PZT, a lock-in amplifier (also known as a phase sensitive detector or synchronous demodulator) can maintain the wavelength at the very center of any selected absorption peak (or dip, depending on your point of view!). The challenging part is to be able to reliably select a specific absorption line to lock to. So, although locking to a given line is fairly simple, the overall electronics can get to be quite complex if automatic line selection is desired, though nowadays, an embedded microcomputer does the line selection and most everything else.

Here are some photos of an iodine stabilized laser based on the classic NIST (National Institute of Standards and Technology, formerly the National Bureau of Standards) design originally described in the paper: Howard P. Layer, "A Portable Iodine Stabilized Helium-Neon Laser, "IEEE Trans. on Inst. and Meas, IM-29, pp358-361, 1980. The photos are actually of two different samples of the NIST design. The first one is of a complete laser head while the others are of a physically similar resonator only where it's easier to see the individual components.

- Iodine Stabilized HeNe Laser Head. The overall appearance is unremarkable with a shutter at the front (the round black thing) and several cables coming out the back (hidden). Leveling "feet" would often be installed be installed in the cast tabs for precise alignment. It is not known if this was a commercial product or built by NIST or perhaps even Hewlett Packard based on the NIST design. But there was an Agilent inventory sticker on the cover, so perhaps this very laser was used to certify HP/Agilent metrology lasers like the 5517A! :) In fact, the base of this laser bears a striking resemblence to the 5517A (though the dimensions don't match). It's a combination of a cast and machined assembly, clearly not made for a one time research project. It may in fact be a Frazier Model 100 FISL (or the NIST version they copied) as the head looks identical to the Frazier laser down to the pattern of holes in its cover. :)

- Iodine Stabilized HeNe Laser Head With Cover Removed. The glow of the Melles Griot 05-LHB-290 two-Brewster HeNe laser tube can be seen within the resonator structure.
- Iodine Stabilized HeNe Laser Resonator - Overall View. The resonator is a rather massive metal structure about 18 inches long.
- Iodine Stabilized HeNe Laser Resonator - Visible Portion of Two-Brewster HeNe Laser Tube. Most of the Melles Griot 05-LHB-290 two-Brewster tube is hidden, but it is mounted via compression O-ring fittings with the high voltage supplied via the BNC connector. The gray blobby thing houses the ballast resistors.
- Iodine Stabilized HeNe Laser Resonator - Iodine Cell. The iodine cell is mounted via compression O-ring fittings between the two-Brewster HeNe laser tube and one of the mirrors. The gold connectors (1 of 2 are visible) are for temperature control of the iodine cell, and possibly a photodiode for monitoring the fluorescence.
- Iodine Absorption Cell Showing Fluorescence From Green HeNe Laser Beam. This shows the same iodine cell having been removed from the ISHL resonator, being excited by a separate green HeNe laser. The yellow-green (with some red) fluorescence inside the iodine cell means some green light is being absorbed and would show up as a reduction in transmitted beam power. (Fluorescence from a 633 nm beam would be in the IR and boring.)
- Iodine Stabilized HeNe Laser Resonator - Photodiode and Beam Sampler. This has an angled plate to provide a small portion of the output beam to a silicon photodiode. Both mirrors are mounted on PZTs for cavity length control and dither (though it's not clear why a single PZT wouldn't suffice for both functions).

Although the laser head does not presently lase, I am hopeful that it will someday. The discharge color of the HeNe laser tube is normal and there is no visible brown crud in the bore indicating that it should be healthy. The iodine cell still has iodine in it based on its response to a green (532 nm) DPSS laser pointer beam. This thing has probably been sitting on a warehouse for years, if not decades (next to the lost Ark), so the non-lasing condition isn't exactly a surprise. However, there seemed to be some type of contamination inside one of the B-windows. So, it may require a replacement 05-LHB-290. The original NIST paper stated that the reflectivity of the OC mirror was only 93 percent, presumably to force single longitudinal mode operation by reducing gain, but this also dramatically reduces output power. However, measurements of the OC mirror in this laser show a reflectivity between 99% and 99.3%, more typical of a normal HeNe laser. Then alignment or some other means could be used to force SLM. It would seem like a better solution to force SLM would be to add a PZT-controlled etalon that tracks cavity length tuning. Then, the output power would be close to the maximum available from the tube - 5 to 10 times higher than this design produces. But I've not seen that anywhere. The paper also states that the laser tube and cavity are 20 and 30 cm long, respectively. On my samples, they are at least 25 and 35 cm. And, their laser tube appears to not be a Melles Griot 05-LHB-290. So perhaps the original prototype was not identical to the versions later reproduced by Frazier (and others), though it's quite clear that Frazier copied nearly every aspect of the laser design down to the controller-in-a-scope and its front panel layout and labeling. ;-)

Putting the iodine cell inside the cavity takes advantage of the high circulating power (approximately 100 times the output power for an OC mirror reflectivity of 99%) and the difference between the gain and lasing threshold based on losses. However, there should be ways to achieve a sufficient boost in sensitivity using an internal mirror HeNe laser tube stabilized to output a single longitudinal mode. With a dual mode polarization stabilized setup, it could be as much as around 2 mW, though the tuning range for the iodine absorption lines may be limited. Two methods that could boost the sensitivity would be to use an external high finesse etalon similar to the cavity of a Scanning Fabry-Perot Interferometer (SFPI) and put the iodine cell *inside* its cavity. That would similarly boost the circulating power by the inverse of the mirror transmission and iodine cell window losses. The SFPI would need to track the tuning of the laser tube and scan in the vicinity of the lasing line to locate the iodine absorption locations. So, some fancy control would be required. Another simpler approach might be to use a custom long iodine cell or one with a large aperture to allow for multiple passes through it, or a pair of internal mirrors to accomplish this, which would be even better.

More on ISHLs:

- Some additional photos of a similar resonator and other components of a complete system can be found at Professor Keto's Iodine Stabilized HeNe Laser (University of Texas). Each of the photos has a fairly complete description.
- And another photo and more info from the NIST Museum's Length - Evolution from Measurement Standard to a Fundamental Constant. It includes a photo of a NIST engineer along with a laser identical to the Frazier 100.

- The National Physical Laboratory (UK) provides both 633 nm and 543.5 nm ISHLs. Search for "iodine".
- Frazier Instrument and Winters Electro-Optics companies also offering ISHLs.

And multi-wavelength iodine stabilized HeNe laser have also been built. See: "A Tunable Iodine Stabilized He-Ne Laser at Wavelengths 543 nm, 605 nm, and 612 nm", J. Hu, T. Ahola, K. Riski, and E. Ikonen, Digest of the 1998 Conference on Precision Electromagnetic Measurements, July 6-10, 1998, IEEE Cat. No. 98CH36254. This one used the tube from a PMS/REO LSTP-1010 5 color tunable HeNe laser with a pair of PieZo Transducers (PZTs) behind the rear mirror (tuning prism) and a lock-in amplifier for feedback control. For these wavelengths, the iodine cell can be outside the cavity, but notice that the red wavelength, 633 nm, is not included. Multi-Wavelength Iodine Stabilized HeNe Laser

The only modification to the laser itself was to add a pair of PZT cylinders between the back of the tuning prism and its mount so that the cavity length could be tuned electronically. The iodine cell and laser power detector are external to the cavity.

What I found curious with this (as well as the NIST laser) is that the laser cavity is way too long to restrict the laser to single longitudinal mode operation as would be required for the system to be useful. The authors of the paper don't appear to address this, nor have I found it mentioned elsewhere.

So I performed a quick experiment using a REO tunable HeNe laser. As expected, with the power in each wavelength maximized, there are multiple longitudinal modes oscillating. And also as expected, there would be a range of the mode sweep cycle where the output would be pure SLM if either the Wavelength Selector or Transverse adjustment were set so as to reduce output power below a specific value, differing for each wavelength as follows:

Wavelength	Maximum SLM Power
632.8 nm	56 μW
611.9 nm	97 μW
604.6 nm	169 μW
594.1 nm	320 μW
543.5 nm	240 μW

These values are very approximate and don't necessarily mean that the laser can be tuned over any significant range and remain SLM as is required to be useful to lock to an I2 line – that would require even lower power. The 543.5 nm SLM power may be somewhat higher than 240 μW but that's as much as my laser wanted to put out at the time. It would appear that 594.1 nm would be a very usable wavelength at higher power, but apparently the authors did not find a suitable I2 absorption transition at that wavelength, or at 632.8 nm either. The latter is rather strange as we know that there are more than a half dozen suitable I2 lines within the normal 632.8 nm gain bandwidth to which the Frazier and NIST lasers can be locked.

The NIST paper describes an ISHL that has an OC reflectance of only 93 percent to raise the lasing threshold and force SLM operation. (Common red HeNe lasers of this size typically have an OC reflectance of 99 percent.) This option is not available for the multi-wavelength ISHL since the authors used a stock PMS/REO tunable laser tube which has a relatively high reflectance (much greater than 99 percent) internal OC. But single mode operation can be forced by misaligning the mirrors or rotating the tube with respect to the iodine cell so the Brewster windows orientations don't line up. And for the yellow and green wavelengths, the effective reflectivity must be higher than something like 99.95% to lase at all.

Assuming this analysis with respect to usable SLM power to be correct, it does explain why direct locked ISHLs typically have very low power. To achieve higher power, some companies offer what is known as an "offset-locked iodine stabilized HeNe laser". With these, a normal SLM HeNe laser with a typical output power of 1 to 2 mW (at 632.8 nm) has its optical frequency phase locked to the lower power ISHL. Implementation is actually easier than it sounds but nonetheless is left as an exercise for the motivated student. ;-)