# Narrowing of high power diode laser arrays using reflection feedback from an etalon

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The spectrum of a high power multielement laser array is narrowed using reflection feedback from an 100 $\mu$m etalon placed in front of the laser. The full width at half maximum (FWHM) of the laser array is reduced by a factor of 2 with only 6% power loss. This reduction in FWHM is useful for optical pumping of alkali metals in the presence of high density buffer gas. © *2000 American Institute of Physics.* [S0003-6951(00)03434-3]

High power (20–100 W) diode laser arrays are commonly used for production of spin-polarized noble gases.[1] The diode lasers are used for optical pumping of Rb or K atoms, which transfer their polarization to $^3$He or $^{129}$Xe atoms by spin exchange. Nuclear spin polarized $^3$He is used in scattering experiments as a source of polarized neutrons.[2] Polarized $^3$He and $^{129}$Xe also have medical applications, they are used for magnetic resonance imaging of lungs and other organs.[3] These applications require several liters (at standard temperature and pressure) of polarized gas. Because the spin-transfer efficiency of the spin-exchange process is typically less than 10%,[4] available laser power is the main limiting factor in producing large quantities of polarized noble gases.

A large spectral width of the diode laser arrays limits the power that can be absorbed by the alkali atoms. High power laser arrays typically have a spectral full width at half maximum (FWHM) of 2–4 nm. The amount of power absorbed by the atoms can be increased by adding high pressure buffer gas to the optical pumping cell and thereby broadening atomic lines.[5] However, mechanical constraints and spin relaxation collisions limit the maximum buffer gas pressure to about 10 atm, which broadens the atomic line to 0.4 nm. About 50% of the power from a diode laser array can be absorbed in a pumping cell with optically thick alkali vapor. The power not absorbed by the alkali atoms can cause overheating of the cell walls and fluctuations in the alkali vapor density. By a relatively small narrowing of the laser spectrum one can significantly increase the amount of power contributing to optical pumping.

Many methods have been used to reduce the linewidth of diode lasers. Single-element lasers are commonly narrowed by using feedback from a grating.[6,7] However, this technique is difficult to apply to diode laser arrays because their output has a very high emittance.[8] Wagshul and Miron[9] narrowed the output of a high power diode laser array using an interference filter. They reduced the linewidth to 0.7 nm with a power loss of 30%. Their technique, however, requires a significant number of additional optical components.

Here we describe a very simple technique for narrowing laser diode arrays using reflection feedback from an etalon. It does not require any additional optical components and works with large diode arrays without beam focusing. The etalon could be incorporated directly into the laser device.

Etalon reflection narrowing of diode lasers was first demonstrated by Hemmati[10] for a 200 mW multimode laser diode. The reflection coefficient of an etalon has a periodic frequency dependence. Figure 1 shows the reflection coefficient for an uncoated quartz etalon with a thickness of 100 $\mu$m that was used in our experiment. Reflection coefficient for a coated etalon is shown for comparison. The thickness of the etalon is chosen so that the gain curve of the laser overlaps only one of the reflection peaks. Because the reflection peaks do not become narrower as the reflectivity of the etalon surfaces is increased, the final achievable linewidth depends on the initial width of the laser gain curve.

Experimental results were obtained with a 40 W diode array from Coherent operating at 795 nm. The array had 19 diodes with emitting area 200 $\mu$m$\times$1 $\mu$m equally spaced along a 1-cm-long stripe. A cylindrical lens attached directly to the diode array collimated the beam (0.3° FWHM divergence) perpendicular to the stripe. The beam divergence along the stripe was 7° (FWHM). The spectrum of the laser was measured with a resolution of 0.02 nm using a grating spectrometer and a linear CCD array. Care was taken to ensure that all elements of the laser diode array were equally

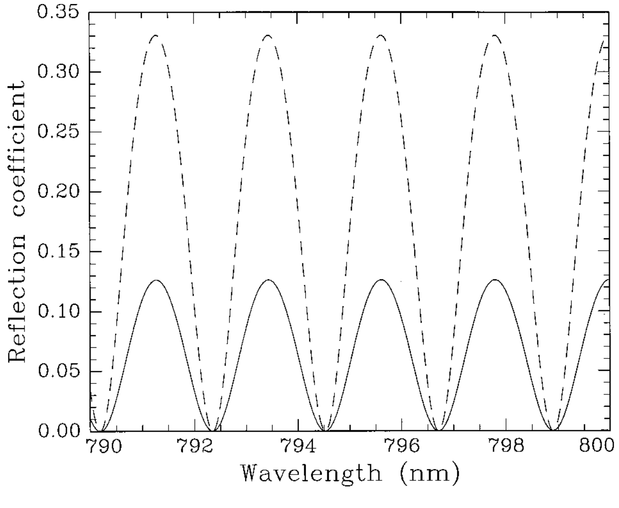

FIG. 1. Wavelength dependence of the reflection coefficient from an 100-$\mu$m-thick quartz etalon. Solid line: uncoated surfaces (3.4% reflection per surface); broken line: 10% reflection per surface.

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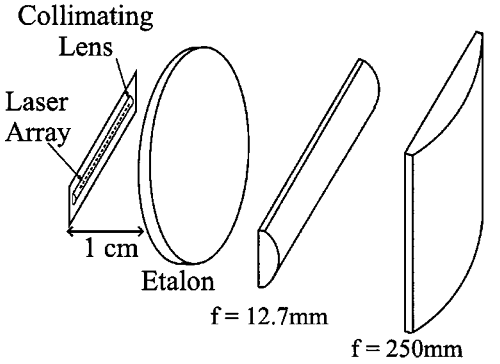

FIG. 2. Schematic of the etalon feedback arrangement. The wedge and thickness of the etalon are greatly exaggerated.

sampled by the spectrometer. The laser beam was focused onto a light diffuser. The light passing through the diffuser was directed through a fiber bundle to the input slit of the spectrometer. We checked that moving various optical components did not change the spectrum.

We found that most effective spectral narrowing was achieved by placing the etalon directly in front the laser, as shown in Fig. 2. The etalon was aligned to direct the reflection back at the laser. The uncoated quartz etalon[11] had a slightly nonuniform thickness, with a wedge of about $7 \times 10^{-5}$ rad. It was rotated around its axis so that the thickness gradient was perpendicular to the long axis of the diode array. This ensured that all diodes saw the reflection from the same thickness of the glass. By translating the etalon in the direction of the thickness gradient the wavelength of the laser could be adjusted to the desired value. The divergence of the laser beam was not affected by the etalon. The laser beam was further collimated by two cylindrical lenses, as shown in Fig. 2. The lens with $f = 12.7$ mm was placed at a distance of 10 cm from the laser and the lens with $f = 250$ mm was placed at 20 cm. This produced a beam with approximately $4 \times 4$ cm square profile at a distance of 60 cm, convenient for optical pumping using a 4 cm diameter cell.

The spectral profiles obtained with and without the etalon are shown in Figs. 3 and 4 for two different laser powers. At the lower power the FWHM was reduced by the etalon from 1.8 to 0.9 nm. At the higher power the FWHM was reduced from 2.0 to 1.0 nm, but the narrowed profile had wide wings. The total laser power was reduced by 6% by the insertion of the etalon. The width of the spectrum was also studied as a function of the distance between the etalon and the laser. It was found that at low power the width did not depend on the distance for distances up to 4 cm, but at high power the width increased for larger distances. Since the laser beam is divergent and the amount of power reflected back to the laser decreases with distance, it indicates that the power in the feedback is insufficient to narrow the laser at high power. The feedback power can be increased by placing the etalon very close to the laser or increasing its reflection coefficient. However, excessive heating of the laser by the reflected light could cause a problem. Another possibility is to optimize the coating on the front of the laser elements to make them more sensitive to external feedback.

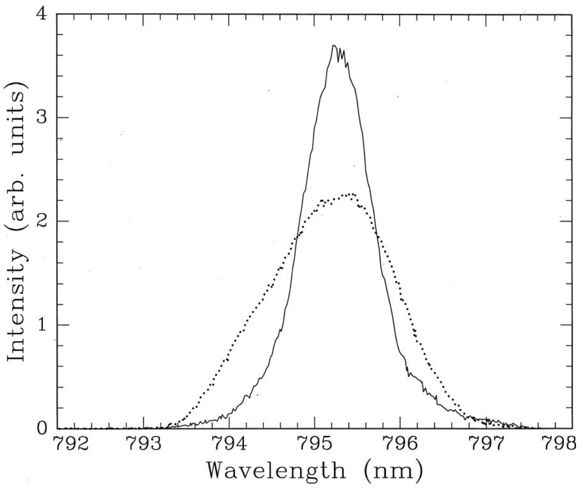

FIG. 3. The laser spectral profile with 100-$\mu$m-thick uncoated etalon (solid line) and without an etalon (dotted line). The laser current is 25 A and the power is 22 W.

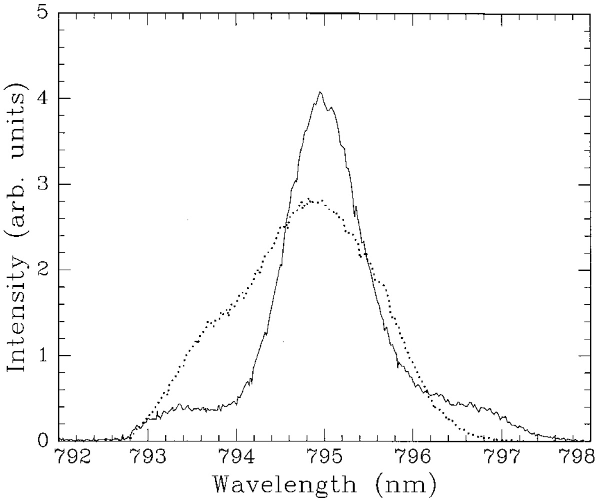

FIG. 4. The laser spectral profile at a higher power with (solid line) and without (dotted line) the etalon. The laser current is 30 A and the power is 27 W.

In conclusion, we have described a very simple technique for narrowing the linewidth of a multielement diode laser array. Further improvement is possible by a more systematic optimization of etalon and laser coatings. This technique can be used to increase the utilization of power in optical pumping of alkali atoms.

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