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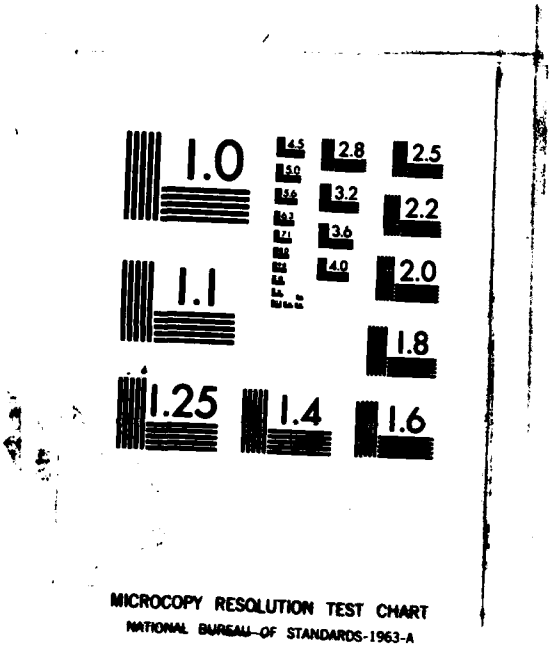

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FIVE TIMES COMPRESSION OF MODE-LOCKED ARGON ION LASER PULSES

BY

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ABSTRACT

We report a five times compression of the 110 ps , 11 nJ pulses from a mode-locked argon ion laser. The pulses are frequency broadened and chirped during passage through a polarization conserving single-mode optical fiber 90 m in length, then compressed by a diffraction grating stage to 22 ps.

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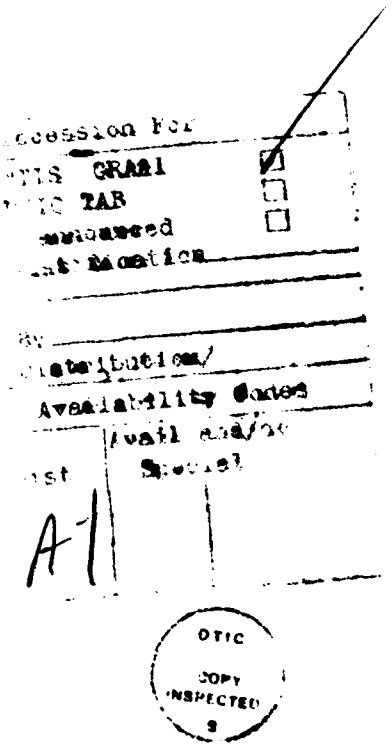

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INTRODUCTION

For short input pulses, such as the ones generated by mode-locked dye lasers, it is possible with a short length of optical fiber to take full advantage of the combined features of self-phase modulation and group velocity dispersion to generate linearly chirped pulses, as shown recently by Grischkowsky, et al.[1-4] and Shank et al.[5] Pulse compressions of more than an order of magnitude have been achieved by sending this frequency broadened and chirped output of the fiber onto a dispersive diffraction grating delay line.[3] We demonstrate that the same technique can be used to compress the longer temporal pulses from a mode-locked argon ion laser (with easy extension to frequency doubled, cw mode-locked Nd/YAG pulses) despite the less favorable conditions of narrower initial bandwidth and lower peak power.

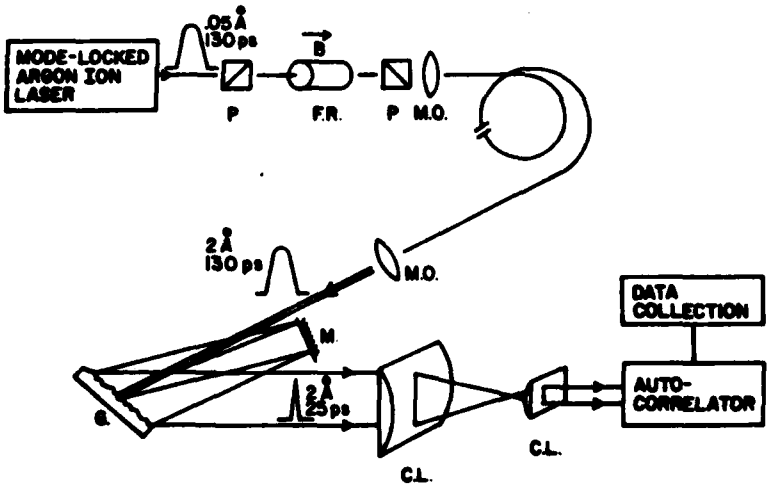

FIG. 1 *Schematic diagram of the experimental apparatus: P = polarizer, F.R. = Faraday rotator, $\vec{B}$ = magnetic field, M.O. = microscope objective, G = grating, and C.L. = cylindrical lens*

The experimental apparatus is shown schematically in Fig. 1. The laser source is a Spectra Physics model 171 mode-locked argon ion laser operated at 5145 Å. Typical working conditions were 850 mW output power at 80 MHz repetition rate. The pulse width (FWHM) was 110 ps, as monitored by a fast photodiode (Spectra Physics, model 403B) and a sampling oscilloscope (Tektronix model 7603, 7S12 sampling head model S-6).

The optical fiber used in these experiments was provided by Dr. Stolen of Bell Laboratories. It has a 2.8 μm pure silica core with an elliptical borosilicate cladding and an index difference of 0.0089. The characteristic properties of this fiber have been described in detail by Ramaswamy, Stolen et al.[6] The light was coupled in and out of the 2.8 μm core of the fiber by

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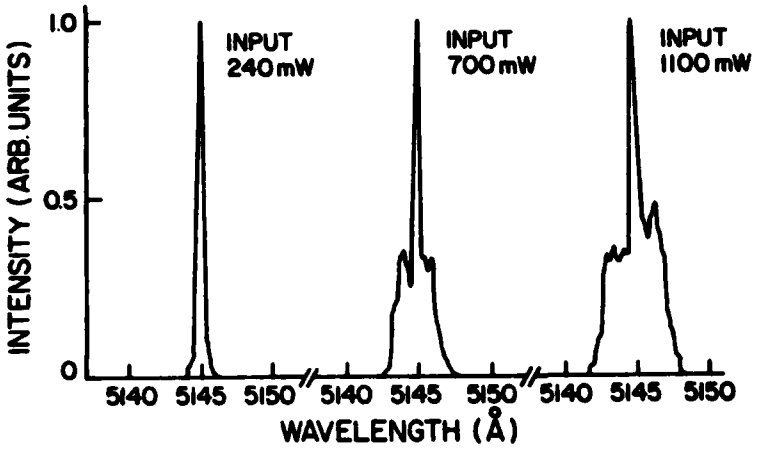

FIG. 2 *Frequency spectra of the pulses at the output of the fiber for three different input powers. The monochromator resolution-limited peak due to non-broadened light transmitted through the cladding was included for comparison.*

a 10x or 20x microscope objective. By careful alignment of the polarization along one of the principal axis of the cladding, it was possible to obtain a 90 to 1 conservation of polarization and a power throughput of 25%. Due to the small core diameter the alignment is very sensitive to vibrations, so values of 10% power throughput and 12:1 ratio of polarization were more typical operating conditions. The fiber length in these experiments was 90 m and the loss at 5145 Å is 40 dB/km.

A Faraday rotator consisting of two polarizers, a fixed field magnet of 2.3 kG and a 1x10 cm Terbium doped glass rod (Hoya Optical FR-5) was used to decouple the laser cavity from back scattered Rayleigh light and the reflections from the microscope objectives and fiber ends. Even with the Faraday rotator, feedback from the fiber considerably degraded the mode-locking when the argon laser was operated above 850 mW.

The pulse widths were measured with a fast diode or with a background free autocorrelator, in which a 2 mm Lithium Formate crystal (Quantum Technology) was used to frequency double the 5145 Å light. The signal from the photomultiplier was recorded by a computer interfaced picoammeter (Keithely, model 416). The bandwidth of the input argon laser pulses was measured with a confocal air-spaced Fabry-Perot etalon with a free spectral range of 1 cm^{-1} (Quanta-Ray, model FPA-1). At the output of the fiber the bandwidth of the frequency broadened pulses was measured with the Fabry-Perot etalon or a monochromator (Spex, model 1870) operated in first order with a resolution of ~0.5 Å.

The initial argon pulses were close to transform limited with a bandwidth of ~0.05 Å and a pulse width of ~110 ps. Figure 2 shows the bandwidth recorded at the output of the fiber, before the grating, for three different argon ion laser input powers. At 240 mW input power the spectrum was still resolution-limited on the monochromator, even though the bandwidth was already considerable broader than the 1 cm^{-1} (0.1 Å) free spectral range of the Fabry-Perot etalon. At 700 mW input power the bandwidth was ~2.5 Å. Bandwidth of up to 4 Å was achieved with 1.1 W input power. The resolution-limited peak due to the non-broadened argon light transmitted through the cladding was included for calibration in the spectra of Fig. 2. In the pulse compression experiment it was removed by mode strippers and apertures.

Since the generated bandwidth is strongly dependent on the coupling efficiency, under typical operating conditions, the 850 mW input power yielded ~2.5 Å, which represents a ~50 fold increase over the initial bandwidth. The autocorrelation of the pulses at the output of the fiber, before the grating compressor, was essentially the same as that of the input pulses, showing that group velocity dispersion effect is small.

The frequency broadened pulses from the optical fiber were compressed with a dispersive delay line using a single grating (PTR, holographic, 2400 line/mm) in a double pass

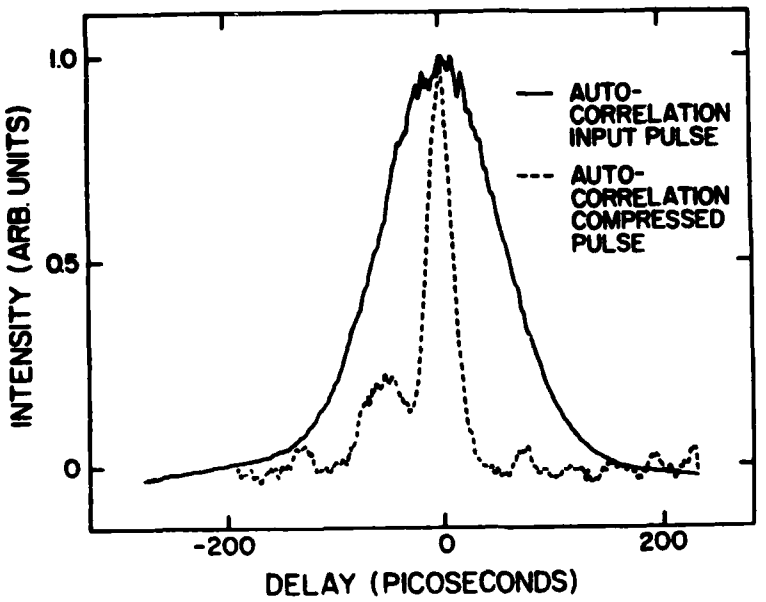

FIG. 3 *Autocorrelation traces of the input and compressed pulses.*

configuration as shown in Fig. 1. The grating was used at near grazing angle to obtain high dispersion [7] and had an efficiency of ~45% per pass. As pointed out to us later by R. Stolen, the design of our grating compressor was not optimal. By using a mirror to reflect the light back on the single grating, instead of using a right angle prism as did Grischkowsky et al,[3] we did not obtain a collimated output beam, and could acheive linear dispersion only in a localized spatial region following the second pass on the diffraction grating.

The shortest pulses were obtained with a grating-grating distance of 1.5 ± .1 m, which is close to the value of 2 m calculated for the 15 degree incident angle.[8] Figure 3 shows the autocorrelation traces of the input and of the compressed pulses. Due to poor alignment of the autocorrelator, the autocorrelation trace of the compressed pulse was asymmetric. For other operating conditions secondary peaks symmetrically centered with respect to the main peak have been recorded. Such secondary peaks are expected for pulses which are not linearly chirped over the full bandwidth, as is likely to be the case here due to the narrow initial bandwidth, low peak power and moderate fiber length.[9]

In order to compress the 110 ps pulses, the grating stage must introduce a ~3 cm path length difference between the leading blue edge and the trailing red edge. After compression by the grating stage the beam was a band ~2 mm high and ~30 mm wide. A cylindrical telescope was used to reduce the asymmetry in the beam to 2 x 5 mm. An alternative way to reduce the astigmatism is to greatly increase the beam diameter before the grating stage, then reduce it with spherical lenses. Clearly a scheme for linear compression without beam shape deformation is desirable. A possible candidate might be the near resonant absorption in metal vapor used by Nakatsuka and Grischkowsky to compress dye laser pulses.[10]

In summary we have demonstrated the use of optical fiber and a diffraction grating stage to compress by a factor of five the 110 ps, 5145 Å pulses from a mode-locked argon ion laser. Given the large bandwidth generated in the optical fiber an additional factor of 10 in compression is theoretically possible. A lower loss single mode fiber would be desirable to take full advantage of this technique.

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