ULTRAHIGH SPEED CRYOGENIC LASER DIODES FOR BROADBAND OPTICAL FIBER LINK APPLICATIONS

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ABSTRACT

In this paper, we present the first systematic study of the temperature dependence of the high speed performance of various laser diodes from room temperature down to 10K. We found that as the threshold current of these diodes decreases by at least an order of magnitude at low temperatures, the modulation bandwidth is dramatically improved. The best result is 27 GHz at 100K for an InGaAsP multiple quantum well laser. We also present experiments on a broadband optical fiber link utilizing a cooled laser diode as a transmitter for 10 Gb/s digital data transmission and 28 GHz carrier video delivery applications.

I. INTRODUCTION

High speed optical fiber communication and data transmission requires high speed laser diode transmitters. Most of these laser diodes operate at or near room temperature. However, for some applications, a cryogenic transmitter may be desirable. For example, low power ultrahigh speed superconducting digital circuits are promising for high speed optical fiber communication applications. There have been very few studies of the low temperature properties of laser diodes [1]. In this paper, we present our studies of the temperature dependence of the high speed performance of various laser diodes for broadband optical fiber link applications. Our best result was obtained on an InGaAsP multiple quantum well (MQW) laser whose modulation bandwidth increased from 10 GHz at 300K to 27 GHz at about 100K. Our studies indicate the potential for utilizing directly-modulated cooled laser diodes for ultra-high-speed optical fiber link applications. We also present experiments using a cooled laser transmitter for 10 GHz digital data transmission and 28 GHz carrier video delivery applications.

II. CRYOGENIC EXPERIMENTAL SET-UP

In Figure 1, we show the experimental set-up for laser diode high frequency network analysis at cryogenic temperatures. The laser diodes are packaged with a K-connector submount which allows for characterization from DC to 40 GHz.

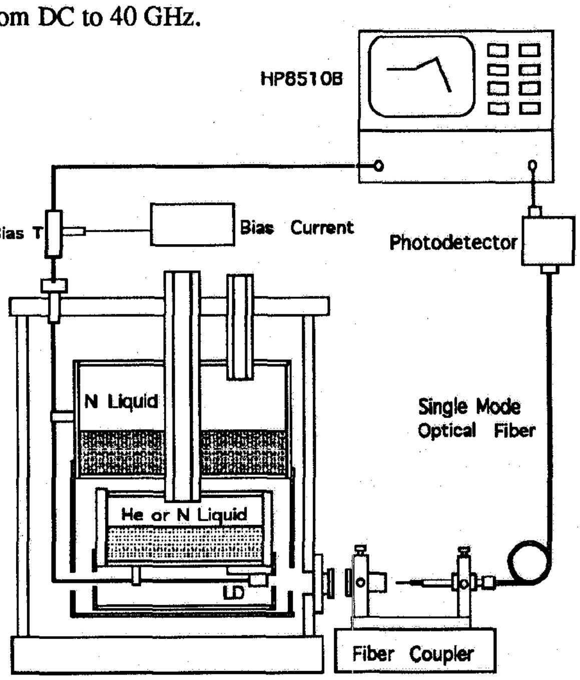

Figure 1. The experimental set-up for studies of laser diodes at cryogenic temperatures.

The laser diode package was mounted on the cold-plate of an Infrared Lab two-stage cryogenic dewar that can be used for both liquid nitrogen and helium. The system is capable of DC to 40 GHz measurement, and temperature regulation from 300K to 5K. The laser diode output was collimated by a GRIN rod lens, and coupled to a single mode fiber. A New Focus 1011 45GHz photodetector was utilized for electrical frequency or time domain analysis. Optical spectrum analysis was also performed. The threshold current measurements were done separately with large-area photodetectors directly collecting laser output from the optical window.

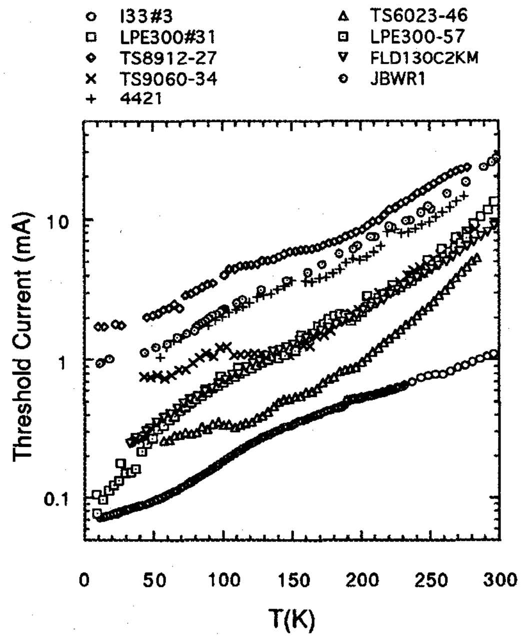

Figure 2. The temperature dependence of the threshold currents of various laser diodes.

III. EXPERIMENTAL RESULTS

We have studied the temperature dependence of the threshold current of a variety of laser diodes. We found that the threshold current of laser diodes decreases by more than an order of magnitude for a temperature change from 300K to 10K. In Figure 2, we show the temperature dependence of these laser diodes, which are listed in Table I. The lowest threshold is 70 μA at 10K for an InGaAs multiple quantum well laser (I33#3). The large reduction of the threshold current is presumably due to a dramatic increase of the optical gain and a reduction of carrier nonradiative recombination at low temperatures[2].

We have systematically studied the temperature dependence of the modulation response of several laser diodes. All lasers under study show an improvement of the modulation response, though to different degrees. In Figure 3, we show the temperature dependence of the modulation bandwidth of the laser diode. One can see that the maximum modulation bandwidth increases from 10 GHz at room temperature to about 27 GHz at 80K.

Table I. Laser Diodes List

Laser	Material	λ (μm)	Structure	Origin
LPE300-57	InGaAsP	1.3	Bulk	Bellcore
LPE300#31	InGaAsP	1.3	Bulk	Bellcore
4421	InGaAsP	1.3	Bulk	Bellcore
FLD130C2M	InGaAsP	1.3	Bulk	Fujitsu
TS6023-46	InGaAsP	1.55	SQW	Bellcore
I33#3	InGaAs	0.9	MWQ	UCSB
TS8912-27	InGaAsP	1.55	MWQ	Bellcore
TS9060-34	InGaAsP	1.55	MWQ	Bellcore
JBR#1	InGaAsP	1.55	MWQ	UCSB

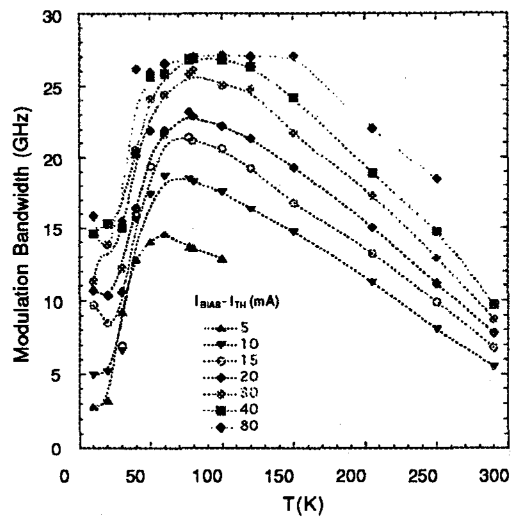

Figure 3. The temperature dependence of the modulation bandwidth of an InGaAsP quantum well laser diode at various net bias currents.

We have also found that with cooling, the electrical-to-optical conversion efficiency increases with decreasing of temperature. For example, the efficiency of JBR#1 (InGaAsP MQW laser) increases by about 25% by cooling to 77K.

IV. OPTICAL FIBER LINK PERFORMANCE

We have conducted an experiment to examine the performance of an optical fiber link with a cooled laser diode (JBR#1) as the transmitter. We examined the bit-error rate of the optical fiber link with the laser diode at 103K and directly modulated by a 10 GHz pseudo-random bit sequence with peak-to-peak signal level of

1V. In Figure 4 and Figure 5, we show an eye diagram of the received signal and the result of the bit error rate of the optical link with the laser diode at different bias conditions. With bias currents larger than 17 mA, the bit-error rate is beyond the instrument detection limit. The testing of digital transmission capability of the optical fiber link is limited by the Anritsu MP1702A error detector.

Recently, there has been increasing interest in millimeter-wave fiber optics systems for personal radio communication and video delivery service applications [4,5]. We conducted an experiment to transmit a video signal on a 28 GHz carrier over 250 meters of fiber with a directly modulated cooled laser diode transmitter. In

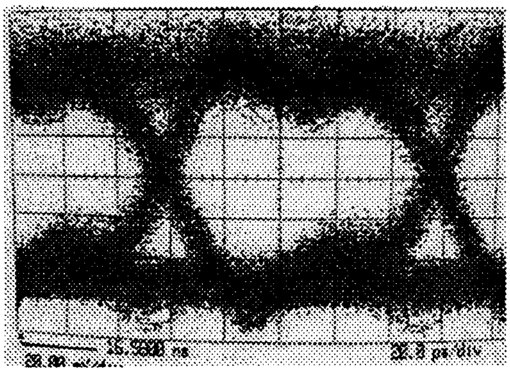

Figure 4. The eye diagram of the transmitted 10Gb/s pseudorandom bit sequence by the cryogenic optical fiber link.

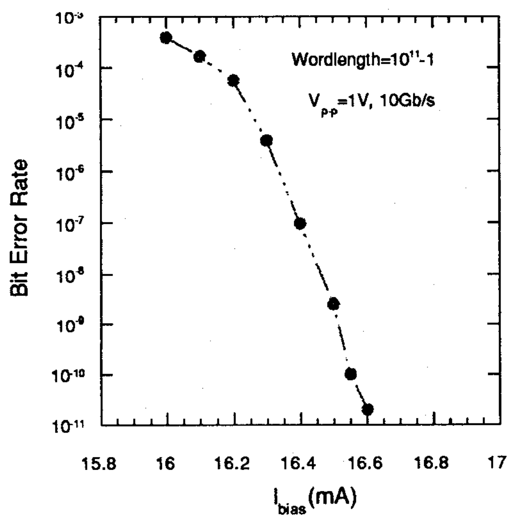

Figure 5. Bit error rate of the optical fiber link with the laser diode transmitter at 100K and at different bias conditions. The bit rate is 10 Gb/s and the word lengths is 2^{11}-1.

Figure 6, we show the schematic diagram of the experimental set-up. The down converted video signals are displayed on a video monitor, or sent to a spectrum analyzer for analysis. With a non-optimized configuration, we obtained a recovered video signal with an S/N ratio of about 40 dB. In Figure 7, we show the baseband video signal, received up-converted signal, and the down-converted baseband video signal.

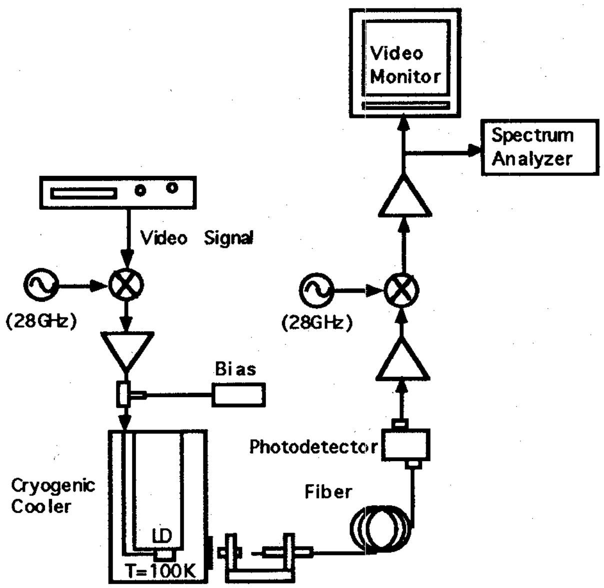

Figure 6. The experimental set-up for 28 GHz video delivery over the utrahigh speed cryogenic optical fiber link.

V. CONCLUSION

We have shown that by cryogenic cooling, one can obtain significant performance enhancement of diode lasers, most notably the large reduction of the threshold current (down to 70 μA), a large increase of modulation bandwidth (up to 27 GHz), and increase of the E/O conversion efficiency. With an optimized design of laser diodes for low temperature operation (e.g., reduction of device parasitics, incorporating DFB structures with tailored wavelength for low temperature operation, etc.), one can obtain an even larger performance improvement. With progress toward the economical and compact cryo-coolers, cooled laser diode transmitters show great potential for a range of high-speed optical fiber communication and data transmission applications.

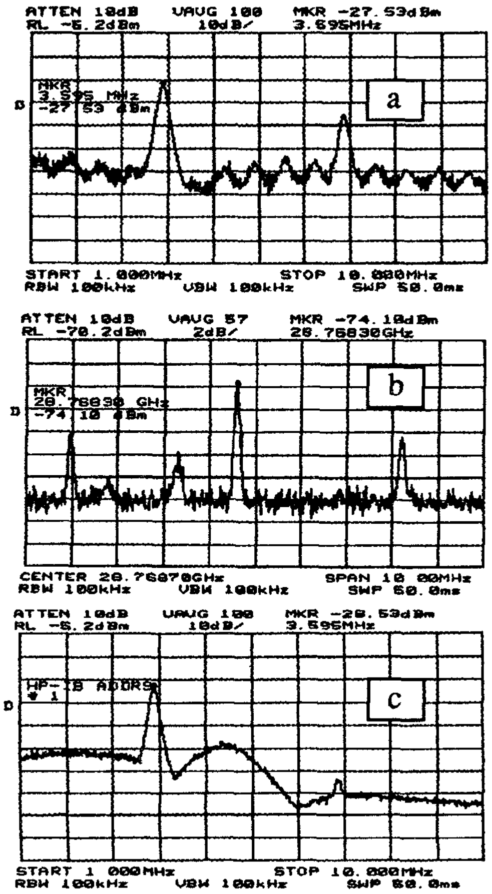

Figure 7. (a) baseband video signal; (b) received up-converted signal at photodetector; (c)down-convered baseband signal.

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