LINEAR LASER FOR CATV APPLICATION

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Abstract - The structure and the properties of a laser that delivers up to 7 mW per face linear optical power with respect to the current are described. The lasers are fabricated from GaAs-GaAlAs wafers grown by the liquid phase epitaxial technique. By carefully controlling the waveguide dimensions with proton implantation, we have substantially improved the linearity. The second and third harmonics are respectively less than 55 dB and 65 dB below the fundamental at 70% modulation. The signal to noise ratio is typically less than 65 dB. The laser has been used to transmit 12 channels of TV signal through a single fiber of more than 1 mile long without deterioration of the picture quality.

I. INTRODUCTION

In a conventional CATV system, the base band signal is carried by carrier waves which propagate through the cable. At the receiving end, a TV receiver demodulates the carriers and displays the information from the base band signal on the screen. In order to be competitive with this conventional system, a fiber optic CATV should be designed in such a way that minimum interfaces between the transmitter and receiver are introduced. This can be achieved by using the carriers to modulate the source light. The light is then sent through an optical fiber. A photodector at the receiving end is used to recover the signal which is subsequently fed to the conventional receiver. In effect, a light source, a piece of fiber and a photodector is used to replace the conventional coaxial cable.

This analog system will be basically simple and cost effective if two requirements are met. The first is that the carriers are faithfully recovered at the receiver for distortion free signal transmission. The second is that the light source must have a broad bandwidth 50 MHz to 250 MHz. The former requires a high degree of linearity in the light output vs. the current input of the light source. The latter requires a light source that is fast enough to respond to the modulation of the carrier frequencies. A properly designed injection laser diode can meet the above two requirements. In this paper, we describe the structure, fabrication, properties and performance of such a laser.

II. STRUCTURE OF A HIGHLY LINEAR LASER

An injection laser is a semiconductor p-n junction device which emits coherent light upon application of a forward bias. Its use as a light source for fiber optic communication is particularly suitable because of small size, high coupling efficiency, direct modulation capability and easy interface with conventional electronic circuitry. There are many different kinds of injection lasers. Among them, the stripe-geometry GaAs-GaAlAs double heterostructure lasers are the most developed and reliable devices which have been widely used since its introduction in the early 1970's. Most of the previous applications of the GaAs-GaAlAs lasers however, concerned only with using the laser as a light source; the problems associated with the linearity, and self-pulsing and relaxation oscillation which limit the bandwidth for modulation and are commonly observed in an injection laser were never considered serious. It was until a few years ago, when the lasers were used in the fiber optic area for data transmission, the problems of linearity and modulation rate started attracting wide attention. Many new structures have since been developed to improve the linearity and suppress self-pulsing and relaxation oscillation. We have developed a laser structure which possesses high degree of linearity and does not show self-pulsing and relaxation oscillation.

The structure of the laser is shown in Figure 1. The size of the laser is typically 380 μm long x 250 μm wide and 100 μm thick. It consists of four epitaxial thin crystalline layers on a GaAs substrate. The epitaxial layers are grown by the liquid phase technique. Fig. 1 shows a very thin p-type GaAs layer which is sandwiched between the two GaAlAs layers containing 24% Al. The interfaces between the GaAs layer and the two GaAlAs layers consist of two heterojunctions and hence the name double heterostructure. The two GaAlAs layers have larger energy gap than the GaAs layer. The larger energy gap produces two potential barriers at the heterojunctions. When a forward bias is applied, the positive and negative charge carriers are confined in the thin GaAs layer by the potential barriers and are forced to recombine. The emitted recombination radiation is further confined and guided in the GaAs layer because the layer has a higher refractive index than the two surrounding GaAlAs layers. Sufficient optical gain can be generated in this GaAs active layer by the interaction between the emitted protons and the charged carriers. As the forward bias increases to the point called the lasing threshold, the optical losses caused by the absorption and scattering are overcome by the optical gain. The laser oscillation can occur if a pair of mirrors is provided. In the case of semiconductor lasers, the mirrors are usually formed by a set of crystalgraphic planes and therefore no external mirrors are needed.

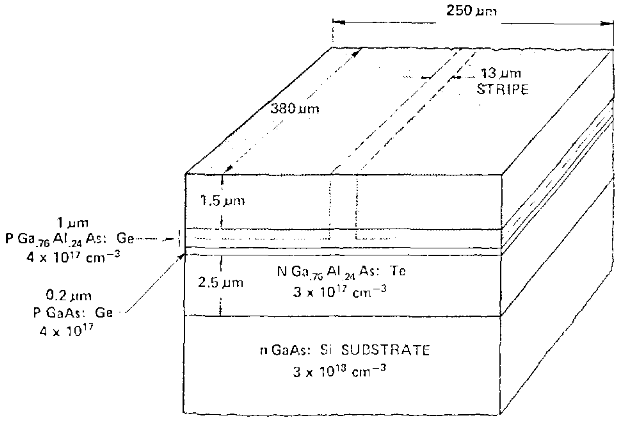

Fig. 1 Layer Structure of the Stripe-Geometry Double Heterostructure Laser.

At a typical threshold current density of $1KA/cm^2$, it requires one ampare to operated a laser with the dimensions shown in Fig. 1. Thus, even for such a small device, a very efficient heat sinking must be used in order to achieve CW operation. Futhermore, such a device generally exhibits multimodes as well as multi-lasing filaments in the plane parallel to the junction. The size of the filament is between 5 to 10 μm. The concept of a stripe-geometry laser is based on the idea that by forming a stripe contact of the size of a filament, one should excite only one filament. In addition, the total current required to operate the laser is greatly reduced and thus is favorable for CW operation without using an elaborate heat sink. The waveguide dimensions in this case is thus defined by the two heterojunctions in the vertical direction and by the current spread in the active layer in the horizontal direction. Because of the dimensional asymmentry and difference in waveguiding mechanisms in both directions, the light pattern diverges 45° vertically and 10° horizontally.

III. PROPERTIES OF A HIGHLY LINEAR LASER

The light output vs. current input characteristics is shown in Fig. 2(a). The light intensity increases very slowly initially. As the current increases beyond the threshold of the laser, the light intensity increases very rapidly. The degree of linearity of the laser is determined by the behavior of the light output with the input current in this range. If the waveguide dimensions are not stable with respect ot the current variation, poor linearity results. In the extreme case, a kink in the output as shown in Fig. 2(b) is observed This nonlinearity is unacceptable in the CATV system.

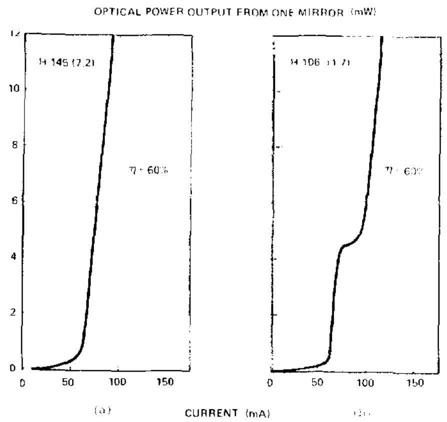

Fig. 2 Output Characteristics of Linear and "Kinked" Lasers.

In most of the commercially available lasers, the stripe contact is formed by cutting a stripe opening on an insulating layer deposited on the surface. Because of the finite distance of the active layer from the surface, the current spreads substantially by the time it reaches the active layer. Since the extent of the current spread depends on the current, the lateral waveguide dimension also changes with current. This type of laser, although is simple to make, often shows poor linearity as well as poor transverse mode stability. On the other hand, our laser uses proton implantation to define the stripe. The implanted region as shown by the shaded region in Fig. 1 turns into semi-insulating and hence only the stipe region can conduct current. Furthermore, the current spread can be controlled by the implantation depth. If the implantation depth is equal to the distance of the active layer from the surface, the current spread in the active layer is greatly minimized. Consequently, we have a much better defined waveguide with respect to the current variation and hence the superior linearity and more stable transverse mode structure.

For analog modulation, a constant current greater than the threshold value is used to bias the laser. The TV carrier shgnals are superimposed to produce the modulation. The bias current and modulation depth are then adjusted to obtain minimum distortion and maximum signal to noise ratio. It is important to point out, however, that distortion can still be introduced by operating the laser improperly even though the laser is perfectly linear. As is common to all light emitting devices, the laser properties are sensitive to the temperature variation. The temperature variation causes the threshold current to change which in turn shifts the curves in Fig. 2 horizontally. The shape of the curves remain unchanged. Thus, for a constant bias current, the bias power can fluctuate in an fluctuating ambient. This can cause an apparent nonlinearity in the light output vs. current input characteristics.

It is, therefore, required to develop some means to stabilize the bias point for distortion free transmission. We have designed a feedback curcuit which is capable of keeping the laser operating at a constant output power. A photodector placed near one of the mirrors is used to detect the laser light. The signal from the photodector is amplified and fed into the base circuit of a transistor to control the collector current which passes through the laser. The rf modulation signal can be applied directly to the laser through some appropriate impedance match network. Because the slope of the light output vs. input current (Fig. 2(a)) is quite steep, only a small input signal is required to obtain relatively deep modulation. For example, a 0.75 volt peak to peak rf signal can produce more than 70% modulation when the laser is in series with a 70Ω resistor and is directly connected to a 75Ω input source. An even smaller voltage can be used if an appropriate impedance match network is used. Fig. 3 shows an optical transmitter designed for transmitting 12 channels of TV signals through a single fiber. A transformer was used to match the 75Ω system to an 18Ω input. It also incorporated a thermal electric cooler which ensures the operation of the laser at 25°C even the ambient temperature gets as high as 70°C.

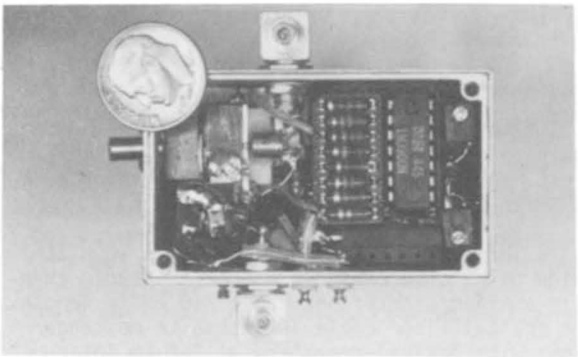

Fig. 3 A CATV Optical Transmitter.

The frequency response of the package is essentially flat from 10 MHz to 280 MHz. In this frequency range, second and third harmonics are typically less than 55 dB and 65 dB respectively below the fundamental at 70% modulation when the laser is biased at 3 mW. For a 12 channel input, the bias point and modulation depth were adjusted to give maximum signal to noise ratio and minimum cross modulation. A signal to noise ratio of less than 65 dB with cross modulation of less than 60 dB was obtained. The transmitter was used to transmit 12 channels of TV signal directly from an antenna through 1 mile of optical fiber without any visible distortion.

IV. CONCLUSION

Because of its large bandwidth, the injection laser is suitable as a light source for fiber optic CATV application. The simplest and most economical CATV system, however, demands high degree of linearity on the light output characteristics of the laser. We have been able to make such high quality lasers by properly controlling the waveguide structure of our laser.