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Equipment to support research into novel fiber optic devices has been acquired. Tunable lasers near 1.3 um and 1.55 um and a polarization controller to characterize the functionality of uoptical devices and circuits based on uresonators were purchased and inserted into a comprehensive guided wave device test system. The 1.3 um laser was donated by SDL, Inc. And was offered as a cost share to the DURIP funds. A comprehensive suite of RF and optical test equipment to characterie the operation and physics of monolithic modelocked lasers was also acquired. This includes a 40 GHz sweep oscillator, an optical spectrum analyzer, an interferometric spectrum analyzer, an RF amplifiers and preamps. This equipment will accelerate the comprehensive characterization of devices and advance the understanding of their operation

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Final Report

Contract Number F49620-97-1-0383
Tunable lasers for investigation of fiber optic devices

1997 DURIP Program

Submitted to
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August, 1998

Abstract

Equipment to support research into novel fiber optic devices has been acquired. Tunable lasers near 1.3 μm and 1.55 μm and a polarization controller to characterize the functionality of μoptical devices and circuits based on μresonators were purchased and inserted into a comprehensive guided wave device test system. The 1.3 μm laser was donated by SDL, Inc. And was offered as a cost share to the DURIP funds. A comprehensive suite of RF and optical test equipment to characterize the operation and physics of monolithic modelocked lasers was also acquired. This includes a 40 GHz sweep oscillator, an optical spectrum analyzer, an interferometric spectrum analyzer, an RF spectrum analyzer , and RF amplifiers and preamps. This equipment will accelerate the comprehensive characterization of devices and advance the understanding of their operation.

1.0 Equipment Purchased with this Grant

This contract supported the purchase of equipment to support research into the design and development of new components for fiber optic systems of interest to the Department of Defense. This equipment is specifically purchased to support research into broad spectral content modelocked lasers for WDM systems, novel integrated μoptical components for WDM systems and long wavelength VCSELs. Several active programs at USC are expected to benefit from this equipment. The specific items purchased under this contract are as follows:

1. New Focus $29,126.88
1 ea. Model 6328-P-FC Tunable diode laser system with center wavelength at 1530 -1550 nm.
This laser system is of use to probe the transmission, absorption, gain, coupling efficiency and reflectivity of various fiber optic components including modelocked lasers, μoptic waveguide components and vertical cavity laser structures.

2. Burleigh Instruments, Inc. $16,906.49
1 ea. HG - 1500 HiFASE Spectrum Analyzer System
This system facilitates the high resolution spectral deconvolution of closely spaced spectral components of the modelocked laser system of interest. It permit us to measure quantitatively and with high accuracy the mode separation between longitudinal modes of a modelocked laser to determine the effects of environmental parameters and device operational parameters on the mode separation in these devices.

3. Hewlett Packard Company $145,528.61*
1 ea. Model 83650 Synthesized CW RF Frequency Sweeper
1 ea. Model 83050A RF Power Amplifier
1 ea. Model 83051A RF Preamplifier
1 ea. Model 8565E RF Spectrum Analyzer
1 ea. Model 8169A Polarization Controller
1 ea. Model 70004A and 70951B Optical Spectrum Analyzer
2 ea. Model HP87421A Power supply

Total $191,561.98

* The actual discounted price of these pieces of equipment was $165,306.73. The difference was paid from another grant.
These pieces of equipment were purchased to power and characterize modelocked lasers and characterize μoptical devices. The frequency sweeper and power amplifier are needed to provide RF modulation to the modulator of CPM lasers. These components were chosen because they were the only instruments capable of operating at 40 GHz with the lowest phase noise. The RF spectrum analyzer was needed to measure the RF purity of the modelocked signal. The polarization controller was needed to control the input polarization of probe signals used in characterizing modelocked lasers and μoptic components. Finally, the optical spectrum analyzer was needed to measure the optical spectrum of modelocked lasers and μoptical components. In the case of the modelocked laser, measurement of the optical spectrum.

4. SDL, Inc. No Cost*
1 ea. Model 8630-M1310 1.3 μm tunable laser system.
This item was valued at $25,000 by SDL and was provided as a gift to support the programs that have been previously identified. This item was offered as a cost share in the proposal.

The HP equipment was ordered in January 1998 and received in April, 1998.

2.0 Proposed Equipment and Justification for Changes

Changes were made in the equipment purchased compared to that which was proposed. These changes were necessitated by program priorities. In the proposal we had proposed the following items:

A. New Focus 1.55 µm tunable laser	$26,500
B. Spectra Physics Optical Parametric Oscillator System.	$165,000
C. SDL 1.3 µm tunable laser system	No Cost

These items were to be integrated into a system for characterization of the dynamic spectral properties of the physical elements of modelocked lasers, µoptic components and VCSELs. These measurements were to augment and amplify measurements of the device characteristics by probing individual physical components of well characterized devices. However, the development of the devices was hampered because insufficient tools were available to routinely characterize basic operational characteristics. This problem arose particularly in the characterization of modelocked lasers. The modelocked regime of operation was found to be a sensitive function of the operating point of the laser. Determining the operation regime in which modelocked operation occurred and correlating that to the materials structure proved to be a time consuming and rate limiting portion of the program. The optical parametric oscillator was primarily justified as a fs probe of the various regions (gain, saturable absorber, and modulator) of the modelocked laser to enable us to refine the structure for optimal dynamic performance. Unfortunately, determining the appropriate structures to characterize with this sophisticated probe was not possible with available device characterization tools. After discussion with the AFOSR program manager (Alan Craig) and personnel at BMDO (Lou Lome), a decision was made to substitute the Burleigh spectrum analyzer and the Hewlett Packard RF and optical equipment (items 2 and 3 of section 1.0) for the Spectra Physics optical parametric oscillator (item B of section 2.0). This substitution gave us a unique capability to drive and characterize 40 GHz modelocked lasers that exists in few university labs at present.

3.0 Impact of the Purchased Equipment on Optoelectronic Component Research

3.1 Monolithic Modelocked Laser Research

The majority of the equipment was purchased to support development of ultrashort pulse monolithic modelocked lasers for use as WDM sources. This work is focused on the development of monolithic colliding pulse modelocked (CPM) lasers emitting near 1.55 µm. The objective of the research is to increase the number of phase locked modes in the operation of these devices through engineering the structure of the devices. A CPM laser is constructed as is shown schematically in Figure 1.

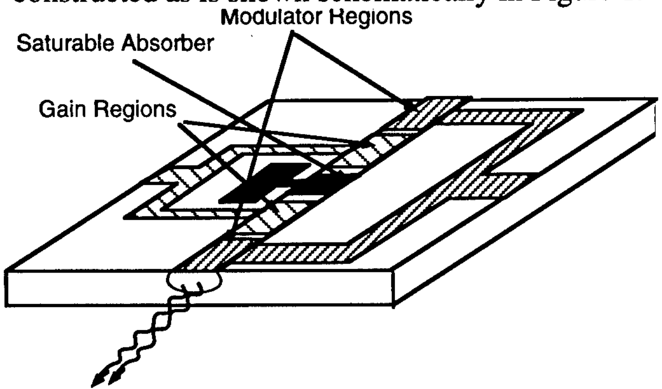

Figure 1 CPM schematic laser design

It consists of gain sections, modulator sections and a saturable absorber section. In operation the gain section is operated CW while the modulator sections are modulated around some operating point at the frequency corresponding to the round trip time of a photon in the device cavity. The RF modulation helps to phase lock the longitudinal modes of the laser. The saturable absorber helps to sharpen the pulse by providing a nonlinear optical element in the cavity. The saturable absorber is biased with a DC voltage to optimize the operation of the device. Typically it is reverse biased to increase the absorption in the spectral region where there is gain in the gain regions and to decrease the optical saturation recovery time. The devices we are investigating are designed for 40 GHz operation, i.e. the cavity is about 1 mm long.

The principle limitation to phase locking many longitudinal modes is the variation of phase across the gain spectrum of the laser. This can arise from dynamic effects such as absorption saturation and gain saturation or it can originate from the static variation of the index of refraction in the various segments. Our intent is to model and design laser structures that have each segment of the laser optimized for the broadest phase locked spectral bandwidth. To do so we must design the static characteristics of the laser to minimize the round trip phase dispersion and invent designs that simultaneously minimize dynamic phase dispersion. This work is currently underway. We have extended existing analyses of CPM lasers to consider the effects of the modulator and asymmetric gain and absorption profiles. These models are being augmented with realistic models of the gain and absorption in quantum well active regions. Simultaneously we are experimentally constructing and testing CPM lasers to determine the effects of design changes on the laser performance. The photograph in fig. 2 below shows CPM laser fabricated in our laboratory.

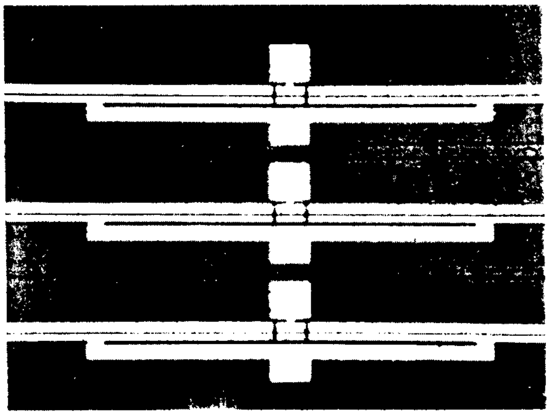

Figure 2 CPM lasers with a 40 μm saturable absorber .

A typical spectrum and the corresponding time dependence of the light output from such a laser operating as a passively modelocked laser is shown below in fig. 3.

A characteristic of the laser spectrum of a CPM laser is that alternate longitudinal modes are absent. The mode spectrum provides an indication of CPM operation in this way. Similarly the longitudinal mode separation provides an exact measure of the round trip frequency of the device. Precise measurement of this frequency and tuning the modulation frequency to this frequency should provide the optimum operational characteristics of the device. Furthermore the dependence of this separation for various device operating parameters provides insight into the group index of refraction of the device.

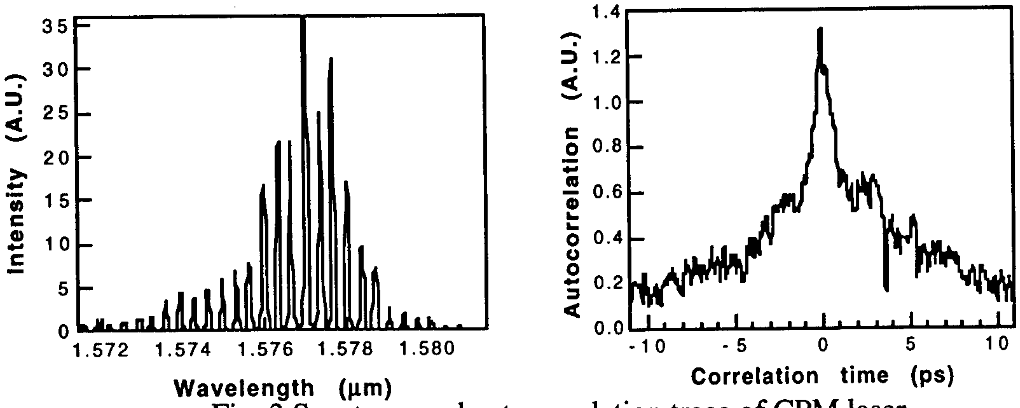

Fig. 3 Spectrum and autocorrelation trace of CPM laser.

Characterization of these devices under passive and active modelocked conditions requires one to accurately measure the mode separation and purity of the RF sidebands. The optical spectrum analyzer purchased with funds from this grant is used to monitor the spectrum of the laser as the various operating parameters are varied. We have found that modelocked operation is a sensitive function of the When CPM operation commences the spectra show the characteristics shown in figure 3. This is a convenient way to determine CPM operation. Simultaneously, the RF sidebands of the spectral output should collapse into a pure single frequency tone that is observable with the RF analysis of the optical output using the RF spectrum analyzer coupled to a high speed photodiode through the RF preamp. However, the resolution of the optical spectrum analyzer is insufficient to measure precisely the mode separation. For that reason we have purchased the Fabry Perot interferometer to precisely measure the mode separation under operating conditions. This instrument has sufficient free spectral range to allow the mode separation between two modes to be determined with a high degree of accuracy. Correlation of the mode separation between adjacent longitudinal modes across the entire spectrum under modelocked and unlocked conditions will enable us to characterize the phase dispersion across the gain spectrum of the device and to determine the effects of operating parameters such as gain section bias, modulator and saturable absorber bias and RF modulation on the index dispersion and modelocked operation.

In addition to these spectral characteristics of the devices the tunable lasers can be used to measure the gain and absorption spectra of the gain section and the saturable absorber section of the device. This is particularly important for gain and absorber media in which the spectra have been engineered selective area epitaxial growth of the region. We are experienced at these measurements since we have previously developed semiconductor optical amplifiers and have measured their gain characteristics.

3.2 μoptic Component Research

High bandwidth optical systems based on WDM concepts require significant advances in the level of integration and the complexity of integrated optical circuits. At present most integrated optical systems for WDM applications are based on gratings or Dragone filters for spectral separation. These components are incompatible with dense WDM systems and more complex functionality that will be required for spectral processing systems of interest to DoD owing to their large and asymmetric geometries. At USC we conducting research to investigate the use of μoptic components to effect densely integrated integrated optical systems. Our system concepts are based on the use of resonant cavity and photonic bandgap technology to reduce the size of functional optical components and to provide greater circuit functionality. A basic building block of this technology is shown schematically in figure 4.

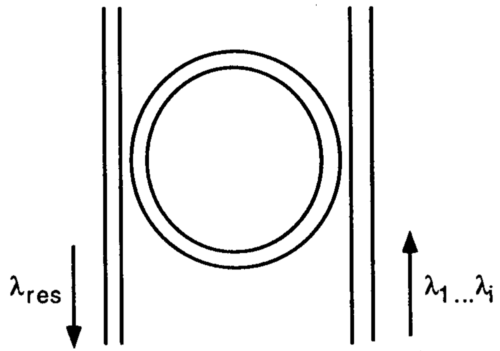

Figure 4 Resonantly coupled waveguide structure

Here we show the schematic diagram of a resonant waveguide coupler based on a µring. The two waveguides are weakly coupled to a high Q resonant ring structure such that only spectral components that are resonances of the ring can be efficient coupled to or from the disk. Such a structure can efficiently couple resonant energy from one waveguide to another. As a passive structure it can act as a channel dropping filter, a resonant detector, a resonant directional coupler, a splitter or a micro bend element. If the ring is active, the device could operate as a WDM laser, a frequency selective switch or a low voltage modulator.

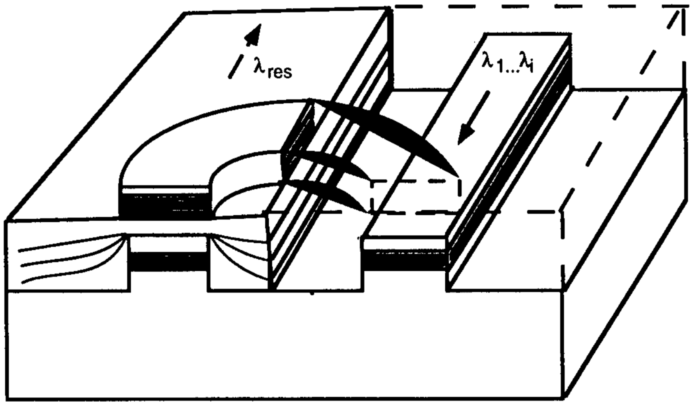

Figure 5 Schematic diagram of a vertically coupled resonant structure.

At USC we have invented a vertically coupled structure that reduces the dependence of the coupling on submicron lithography as is the case for laterally coupled structures. The concept is shown in Fig. 5 where we show a ring structure vertically coupled to two waveguides. Such a three dimensional structure can be fabricated by a variety of means. We have been investigating the use of wafer bonding to achieve this structure. Fig. 6 shows an experimental sample fabricated with wafer bonding.

Figure 6 SEM Micrograph of a vertically coupled resonant structure based on a µdisk that was fabricated by wafer bonding.

The equipment purchased on this grant will enable us to study the spectral properties of these resonant structures. The tunable lasers have sufficiently narrow linewidth and a wide enough tuning range that the resonances of the µstructure can be resolved spectrally. The polarization controller is required to resolve the polarization dependence of the coupling.

1.3 -1.55 µm VCSEL Research

Currently high performance vertical cavity surface emitting lasers are made in the AlGaAs/GaAs materials system by monolithically integrating two high reflectance DBR's and a AlGaAs/GaAs/InGaAs quantum well active region. The availability of lattice matched high index of refractive contrast materials for the mirror pairs makes this device possible. The extension of this device concept to longer wavelengths (1.3 µm and 1.55 µm) where optical fibers are more transparent has been problematic. Materials that emit in these ranges are usually grown lattice matched to InP and the available materials for DBRs have low index contrast. We have been exploring approaches to fabricating very high contrast DBR's that can be monolithically integrated with InP lattice matched active regions. One approach we have undertaken is to utilize air/InP Bragg structures. These are fabricated by selectively removing InGaAs layers from and InGaAs/InP lattice matched structure that has been buried in InP. An example of such a structure is shown in Fig 7. Owing to their fragile structure and to permit heat extraction in the device, these DBRs must be only a few microns in dimension. Thus characterizing their reflectivity is difficult using incoherent light. However, the tunable lasers purchased on this grant will allow us to characterize them more rapidly and accelerate the development of devices.

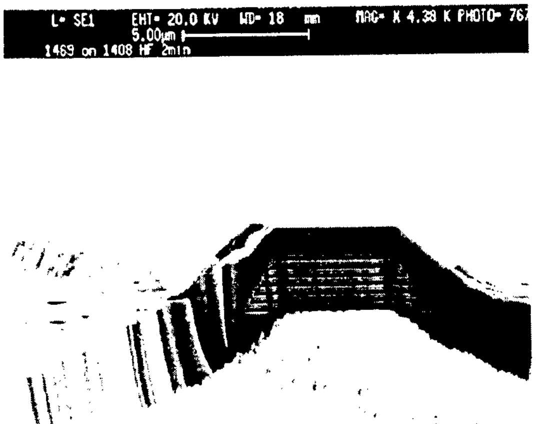

Figure 7 SEM micrograph of an air / InP DBR structure for long wavelength VCSELs.