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Tunable Vertical Cavity Laser and Photodetector for Free Space Interconnection

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1. Introduction

We propose a new concept of high density free space optical interconnection based on wavelength division multiplexing. Our goal is to realized an integrated reconfigurable interconnection between a large number of sources and detectors which can communicate simultaneously. Some possible applications are boards to boards or chips to chips interconnection in computers or other electronic systems. Free space optical interconnection has advantages over wired electric connection in a signal transmission point of view : high speed, large channel density, parallelism, electromagnetic immunity, and low-power consumption. This interconnection is composed by an array of micro-mechanically wavelength-tunable vertical cavity surface-emitting lasers (VCSEL) and detectors, interconnected in free space (figure 1). The wavelength tuning for both, the emitter and the receiver, is expected to be a few tens of nanometer. It's allow us to envisaged quite large interconnection using 8x8 matrices. In order to interconnect the two matrices in free space, we plan to use two optical lens array and some optical structure more or less complicated like a single lens or some diffractive or holographic optical elements (DOE or HOE), depending on the interconnection type.

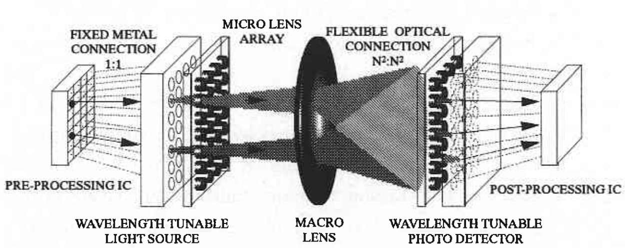

Fig. 1 shematic structure of the free space optical interconnection

2. Micro-mechanical tunable VCSEL

To date, most effort into monolithic continuous tunable semiconductor lasers has been made on edge emitting devices using filter and phase-shift sections to select a particular wavelength. For surface emitting laser (VCSEL) continuous tuning have been demonstrated using both refractive index modulation and external mirror to control the cavity length, but the tuning ranges as for edge emitting type have been relatively small. Recently a new generation of micro-mechanical tunable laser which combine nanofabrication and MEMS technology in order to integrate a movable mirror to tune the emitted wavelength was build at Stanford University (Larson and Harris 97).

In the III-V structure each element of the tunable laser source array is based on the semiconductor coupled cavity (SCC) design (figure 2 and 3). In this design the $In_{0.15}Ga_{0.85}As$ (8nm) /GaAs (10nm) multiple quantum well (MQW) active medium is

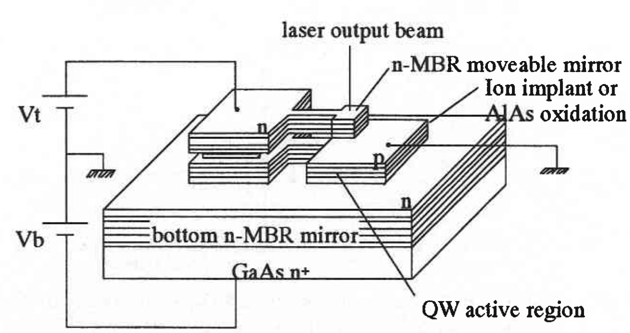

Fig.2 single tunable VCSEL architecture
Vt = tunning voltage - Vb = laser bias voltage

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located inside the $Al_{0.4}Ga_{0.6}As$ cavity whose thickness is a multiple of half wavelength. The *n*-doped bottom MBR consists of 33.5 pairs of GaAs/AlAs quarter wavelength stacks, with thickness 80 nm and 66nm respectively (λ= 950nm). The top multilayer Bragg reflector (MBR) contains a small p-doped $Al_{0.1}Ga_{0.9}As$ /$Al_{0.5}Ga_{0.5}As$ (69 nm, 74 nm) portion directly above the cavity, then a thickness-tunable air gap of thickness an odd multiple of quarter wavelength (1.425μm), before the top *n*-doped MBR $Al_{0.2}Ga_{0.8}As$ /$Al_{0.9}Ga_{0.1}As$ (69 nm, 80 nm x 20,5 pairs).The air gap is realized by selectively etch a so called "sacrificial layer". Wavelength-tuning is achieved electrostatically by reverse-biasing the p-n junction between the n-doped top suspended mirror and the p doped MBR. As the reverse bias increases, the cantilever is attracted down towards the *p*+ contact, changing the reflectivity of the mirror and therefore, the Fabry-Perot wavelength of the device.

This structure was grown on an n^+ substrate by LP-MOCVD at 76 torr and 700 °C. The ohmic contact were performed and test on an AlGaAs LED (Light Emitting Diode) structure. In order to insure continuous wave (CW) operation with low threshold current we need a good electrical as well as optical confinement which is realized by the lateral oxidation of an aluminum layer on top of the cavity. For the single devices realization the last important thing is the releasing of the moveable mirror. The sample structure for the etching test consist of a small MBR type mirror ($Al_{0.1}Ga_{0.9}As$ /$Al_{0.5}Ga_{0.5}As$), a GaAs sacrificial layer and a top MBR type mirror ($Al_{0.2}Ga_{0.8}As$ /$Al_{0.9}Ga_{0.1}As$). There is 2 main step in the etching sequence : non-selective etching of the top MBR and a small part of the sacrificial (GaAs) layer follow by the selective etching of the GaAs to release completely the mirror and the led.

The first etching test were performed by wet etching using for non-selective etching of $Al_X{}^{Ga}1\text{-}X^{As}$ ($0 < x < 1$) a solution of $H_3PO_4/H_2O_2/H_2O$ (1:1:8) and for selective etching of GaAs over AlGaAs a solution of citric acid and H_2O_2 (figures 4-5). We didn't have any problem with the non-selective etching but we must be careful to not over etch. For the selective etching we could removed the GaAs sacrificial layer by the citric acid solution except under the mirror. We try to move the etchant to enhance the lateral etching without any results. In view of all this these difficulties and in order to eliminated the steeking of the release part due to the very high viscosity of the citric acid solution we decide to used a dry etching technique. This allow us to start collaborations with Fujitsu laboratories Ltd. in Japan and IEMN in France.

The dry etching at Fujitsu laboratories was performed trough a 200 nm SiON mask deposit by P-CVD. $SiCl_4$ was used to etch non-selectively the AlGaAs and $SiCl_4/SF_6$ was used for isotropicaly etch GaAs over AlGaAs. The GaAs sacrificial layer under the

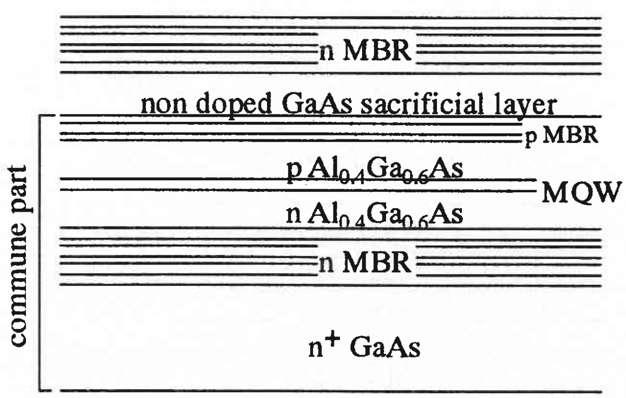


Fig.3　TVCSEL layers structure

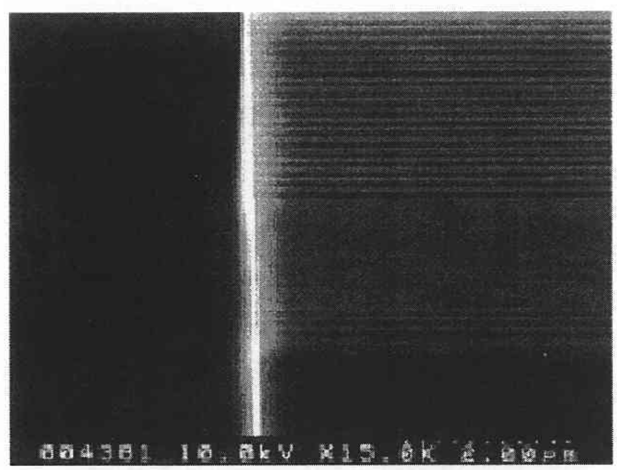


Fig.4　SEM photography of the VCSEL top structure

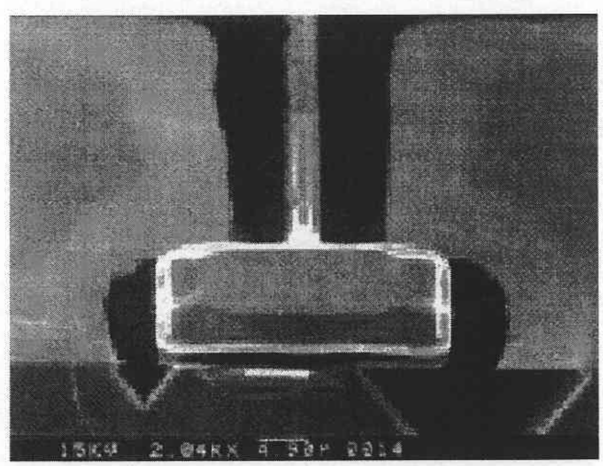
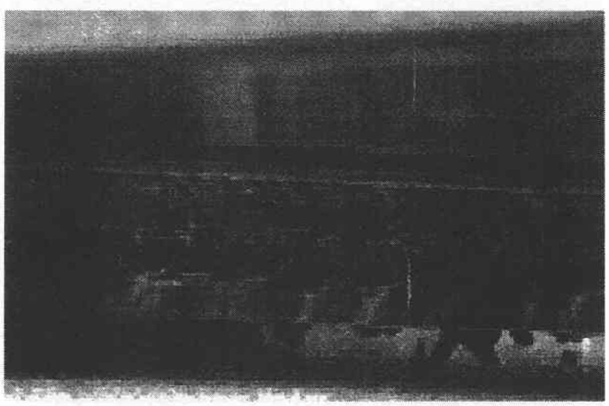


Fig.5　Cantilever structure after wet etching

leg was successfully removed by the $SiCl_4$ but not completely under the mirror (figure 6). If we further increase the etching duration to remove the GaAs under the mirror the suspension leg will be destroyed because of side etch. So we are currently working on the side-wall protection of both the mirror and the leg to avoid this problem as much as possible but also we try to increased the lateral selectivity.

At the "Institut d'Electronique et de Microelectronique du Nord" (IEMN) the etching test was realized on an OXFORD plasmalab 80plus kit. The gases for non-selective and selective etching of GaAs over AlGaAs was respectively $SiCl_4$/Ar and CCl_2/Ar. The etching mask was in this case a p type photoresist. We could successfully released the smallest cantilever type mirror (figure 7). The other structure collapsed on the substrate may be due to the very thick photoresist layer of about 4.5 μm above them. To avoid this the next etching test will be perform with a very thin SiN or SiON layer of about 500 nm.



Fog.6 GaAs sacrifidial layer under the mirror not completely removed

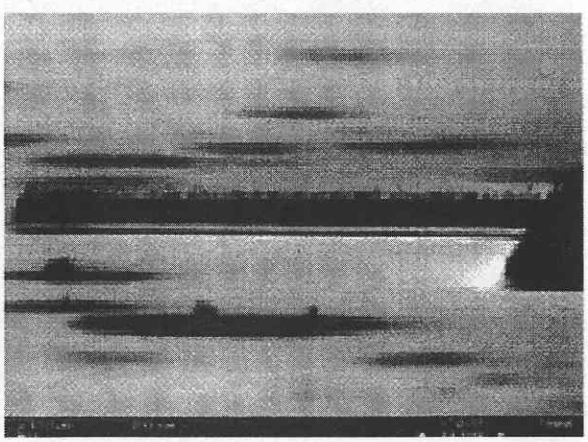


Fig.7 Relased cantilever by dry etching leg = 50μm, mirror = 10μm

3. Micro-mechanical tunable photodetector

The wavelength tunable photodetector is implemented by silicon surface micromachining. It is composed by a photodiode formed in a silicon substrate combined with Fabry-Perot Interferometer (FPI) filter for wavelength selection. As for the tunable VCSEL the wavelength tuning is obtained by squeezing an air gap of thickness a multiple of $\lambda/2$ between the 2 mirrors of the FPI filter using electrostatic forces. To meet the requirement for high density free space interconnection the tunable FPI should have a wide tuning range and narrow transmission spectrum to increase the number of channels. To make narrow full width at half-maximum (FWHM) of the spectrum each mirror is made of high refractive index contrast layer MBR such as SiN/air and SiO_2/Air which allow a small number of pair. A schematic structure of this detector is shown on figure 8. The incident light of a particular wavelength penetrates though the FPI filter and then is detected with the underneath photodetector only when the wavelength matches with the transmission peak of the FPI.

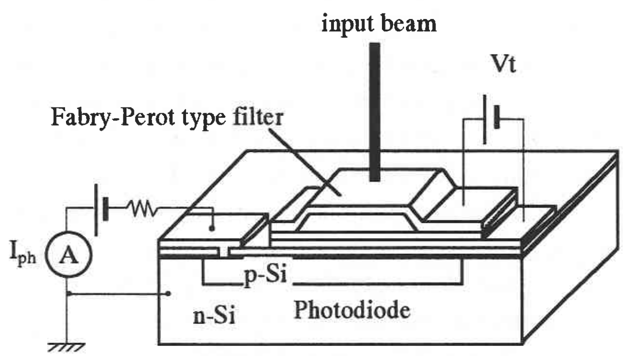


Fig.8 Single tunable photodetector architecture vt = tunning voltage - I_{ph} = photocurrent

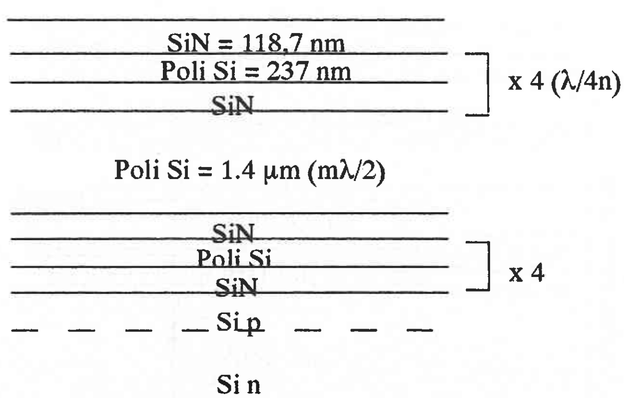


Fig.9 Tunable photodetector layers structure

The details of the layer structure are given in figure 9. The photodiode is formed by boron implantation into a n type Si substrate. The FPI filter is composed by two 5 pairs SiN/polySi MBR type mirror separated by an sacrificial polySi layer of thickness a multiple of half the wavelength to be detected. We are currently working on the Poly Si selective etching in order to create the air gap and the SiN/air or SiO_2/air mirror.

The 2 samples structure for the etching test are has follow : Si substrate oxidized by wet thermal oxidation then for one ; a 2 pairs SiN/polySi MBR and for the other a 2 pairs SiO_2/polySi MBR. The etching mask is a thin chromium layer and the etching pattern are bridges of 100 μm length with many different width, from 30 μm to 1 mm. Before the releasing we etch vertically until the substrate (thermal oxide stop layer) by Reactive Ion Etching (RIE). We used for the selective etching of the polySi and SiN over SiO_2 is performed using SF_6 and CHF_3 is used to selectively etch SiO_2 over the polySi. For the sacrificial polySi layer removal we are investigated 2 different way. By wet chemical etching using KOH or TMAH or in collaboration with Professor M. Esashi's group from Sendai University we use XeF_2 which have a selectivity nearly infinite over SiO_2 (formed by thermal oxide) and a very good one of about 1000 over SiN

4. Conclusion

We proposed a concept of high-density interconnection based on wavelength division multiplexing by using array of micro-electro-mechanical wavelength tunable vertical cavity laser and photodetector. The single devices for both the light source and the detector array are in the process of being realized.

The wavelength tunable laser is developed using III-V semiconductor material. The AlGaAs layer oxidation for electrical as well as optical confinement to proved low threshold current and CW operation has been realized. The dry selective etching using CCL_2 gas has been tested and we have successfully released a cantilever type structure. We are now working on the selective etching optimization in order to be able to release bigger structure. The next step will be the device realization and testing before putting them into matrices.

The wavelength tunable photodetector is realized using silicon based material micromachining. SiN/air or SiO_2/air MBR are employed for the mirrors of the interferometer, and the thin film structures were investigated by using computer simulation to optimize the wavelength selectivity and to maximize the channel density. Preliminary device are under way.

This principle of free space interconnection has a wide range of applications such as switching elements in parallel processors, optical switches, and neural networks that based on flexible optical interconnection.

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