Microsystems and Waferprocesses for Volumeproduction of Highly Reliable Fiber Optic Components for Telecom- and Datacom-Application

Hans L. Althaus, Wolfgang Gramann and Klaus Panzer

Siemens Semiconductors Fiberoptics,
Wernerwekstraße 2, D-93049 Regensburg, Germany

Abstract

In development and fabrication of highly reliable active fiberoptic components, first the application of great fields of microsystemtechniques enabled the break through in volume-production. Micro-mechanical methods allowed the big scale fabrication of microoptical silicon lenses with mthods, machines and materials of the semiconductor technology on wafer. With the simultaneous application of micro-mechanical methods, such as anodic bonding processes of optical components and semiconductor-laser heated solder bonding techniques, it was possible to realize also hybrid integrated fiberoptic subcomponents on silicon wafer with the neccessary dimensions, tolerances and mechanical stability in the submicrometer region.

We have realized a technology with micro-systems that enables on an (about 1mm sq.) chip in a silicon wafer compound the hybrid integration of complete active fiberoptic modules with their different active semiconductor chips and the micro-optics for direct coupling in and out of the SM- and MM-fibers for different applications. With this technology of a compact design of the neccessary materials and components we could assemble components as laser- and detector-modules with the highest standard of microoptical stability and reliability.

With this technique we can use the already in microelectronics well-established low cost production methods on wafer scale also for active fiberoptic components. This means the complete fabrication, burn-in and testing procedures are practicable for example on a 5 inch silicon-wafer. So the main module-functions are separated from the cost intensive packaging efforts. It is rather possible to provide with a standard-submount base-component a fiberoptic product-family for different applications with adapted packages. This means that on the base of these module-subcomponents the volume production as well of low cost as also of high end components for fiberoptics are possible.

As all the essential opto-electrical and mechanical functions are combined in the highly stable subcomponent chip with well adapted materials, in minimal dimensions and symmetrical design, all the derived fiberoptic components can provide the imperative reliability for these products. in some examples we show proposed exploitations of these thechnique for highly expedient realization of fiberoptic transmission systems. One very important field for application of low cost components is the access network. Fiber to the home needs medium datarates (up to 155 Mbit/s) and medium length (up to 10 km). The techniques described here allows to find the optimum between performance and cost for these applications. Using the bi-directional transmission the effort for the bit transport can be reduced near to the level of copper lines. Therefore the German Telekom has installed a lot of subscriber lines using modules for bi-directional optical transmission.

Introduction

Since the application of fiberoptics as an alternative transmission methode, beside the question about the lifetime of the laserdiodes, the question about the long term mechanical stability between the emitter-chip and the glass-fiber rised to an essential significance. This importance was enhanced with establishing singlemode fibers for the most applications of fiberoptics preferably, in telecom. This created for the fiberoptic components industry the technical challenge to realize robust fiberoptic modules, especially lasermodules with a SM-fiber coupling. Neccessary coupling tolerances in the region of 1µm and a fixation with a mechnical stability of less than 0.1µm under all possible operation- and storage-conditions rised to a standard demand.

We know a number of investigations and developments [1,2,3] to solve this technical problem. Most of the solutions were more or less expensive and not suitable for a low cost big scale production. Others could not fulfil the quality demands of the meanwhile established Bell-Core Qualification System for fiberoptic components. This Bell-Core Qualification demands the following most critcal mechanical tests as a) low temperatur storage at -40°C , b) high temperature storage at +85°C and not at least c) slow temperature cycling from -40°C to +85°C for a minimum of 500cycles. The hardness of this tests can be realized if we see that the thermal expansion of suitable metallic package materials is more than 1.5µm for a 1mm package unit where the upper mentioned mechanical stability between fiber and laser must be less than 0.1µm to guaranty a stable light coupling from the laser to the 10µm dia. fiber-core of less than +/-10%. These mechanical requirements beside the self evident electro-optical functions were fulfilled in the early eighties with high effords in hermetical packaging, especially in fiber fixation to the laser chip and the hermetical fiber feedthrough of the metallic package. So the costs of the first industrial produced lasermodules with SM-fiber access were in the region of 1.500$. Fig. 1 shows in a enlarged representation of the laser-fiber connection a typical DIL14-module from this generation. The most cost effective design in this so called pigtail module was the hermetical fiber feedthrough to the package wall directly in front to the laser facet to a distance of about 30µm and its fixation to a common base.

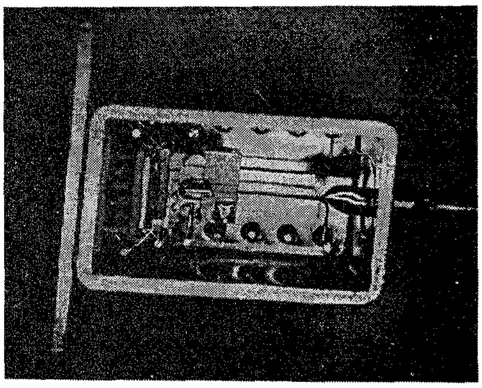


Figure 1. DIL14-Lasermodule with direct fiber-coupling

The next generation of modules with reduced efforts in packaging was possible with the application of separate microlenses between laserdiode and fiber. This step in development enabled a complete new generation of laser modules, where the fiber could be separated from the laser-chip in distances of more than 1mm. This gave the possibility to include only the sensitive laser- and the monitor-chip into the hermetical package. So a number of different cost reduction potentials as

a) using standard low cost packages (TO-Packages) as already used with standard semiconductor components (transistors, fotodiodes, IREDs, etc.) with standard equipment for hermetical sealing (resistance welding),
b)pretesting the components without the expensive fiber oupling on a low cost level,
c) abrication of laser-modules with fixed or detatchable fiber connection.

The subcomponent of this laser-modul generation is the so called TO-Can-Laser. The neccessary micro- or macro-lens for laser-fiber coupling can be fixed, dependent of ist dimensions,
a) inside as micro-lens (dia.<1mm) directly in front of the laserchip,
b) outside as macro-lens (dia.>1mm) or directly as window of the hermetical TO-can. The three design-types have different advantages and disadvantages.

Our approach was the type a) design with the inside lens, because this design has from our point of view the highest cost reduction potential with a simultaneous highest performance [1], if it is possible to realize a reliable highly stable low tolerant fixing-method of the microlens in front of the laser chip.

Our first approach for this micro-optical system was the application of a spherical LaF22-glass-lens with a diameter of 0.5mm and a refreactive index of 1.78. With this lens it was possible to realize enlarged representations from 1:4 to 1:8 from the laser emission window of 0.1µm x 3µm on the coupled SM-fiber core of 10µm dia. In respect to the possible wave-front adaption fom the laser to the fiber gives this possible coupling efficiencies of more than 30% of the emitted front facet light power into the SM-fiber [2]. Fig.2 shows in a 3d view the design of the TO-can laser with integrated ball-lens .

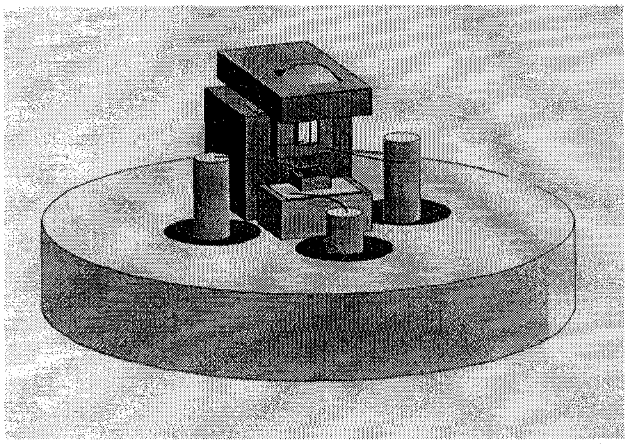


Figure 2. TO-Can Laser with a Glass-Ball-Lens

In this design the first application of micro-mechanics enabled the positioning and fixing of the dia.0.5mm glass-ball-lens in front of the laser diode. The lens was fixed by a glass-solder inside a etched V-hole of the silicon chip. For active alignment of the lens to the laser chip and its fixation, the silicon lensholder chip was the neccessary interconnection element The heating power for melting the solder was directly coupled into the silicon chip.

In this stage of development of TO-can fiberoptic components the first use of the silicon micro-mechanics allowed the simultaneous fabrication of thousands of lensholder chips on a silicon wafer. This essential step from the expensive fine-mechanics in the construction of laser modules to micro-mechanics with synergies to established silicon semiconductor wafer processes (V-groove etching, metallisation for soldering, chip-separation, optical coating) was the first big step to rational fabrication not only of TO-can lasers with integrated lens, but also for the other fiberoptic components as TO-can IRED-diodes and TO-can photodiodes. On the base of this first application of micro-mechnics for fiberoptic components we started in a new redesign-process The approach for all these components was the consistent application of micro-mechanics and micro-optics The extended use of waferprocesses gives the key to a low cost volume producion als of fiberoptic components.

I Development and Realization of Fiberoptic Components

Silicon Submount Laser Module

The special character of a edge-emtting fabry-perot laser diode allowes only a complete testing of this chip after mounting on a submount or complete packaging. This most expensive production principle prevented the usual semiconductor wafer production methods for laser diodes

With using microsystems in our redesign concept of the TO-can laser we could realize a complete wafer-production and wafer-testing method also for fabry-perot laserdiodes. The principle is the transformation of lateral emission to a vertical transmission by using micro-mechanical produced micro-optical 45deg. mirrors in front of the both emitting laser facets.The general design is shown in Fig. 3

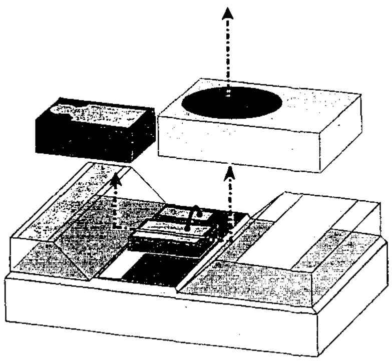


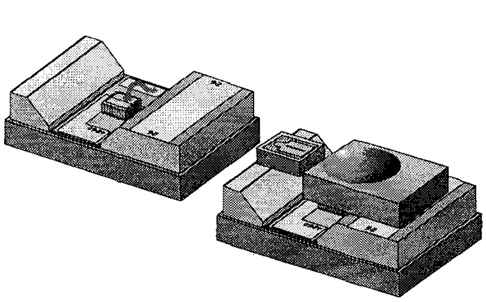
Figure 3. General Design of Veritcal Emission of FP-Laser

The common base of the laser-chip and the 45deg mirrorbars is a silicon-submount chip, which is simultaneous the neccessary heat sink for the laser-diode. The extraordinary semicoductor material silicon offers here all the needed performances for the hybrid integrated lasermodule:

a) as heatsink a good heat-coductivity,
b) as the most used semiconductor material the best established wafer-processing methods up to 6inch waferprocesses,
c) as base-material the needed high solidity with simultaneous very low expansion coefficient and at least
d) as optical transparent material for wafelenghts higher than 1100nm excellent optical characteristics with a refractive index of n=3.5.

The complete hybrid integrated laser-module with monitor-diode and collimating lens can be seen in Fig.4.

Laser - Submount



submount assemblied with lens and monitor diode

Figure 4. Hybrid Integrated Laser-Module Chip

In this design the neccessary lens in front of the laser chip is realized as an entire silicon lens-chip. Here silicon is used as an optical material. The refractive index of 3.5 allows the use of a spherical surface with a radius of more than 0.6mm to realize the corresponding optical focus of the divergent laserbeam out of the chip.

The backside monitor-diode chip is due to the emission wavelengths of the laser of more than 1250nm as ternary diode on InP-substrate. The design of the complete TO-Laser is shown in Fig. 5. We see without changing the outer package and optical dimensions the laser could be realized in a very compact inner design (see in comparison Fig.2).

Laser in TO-can

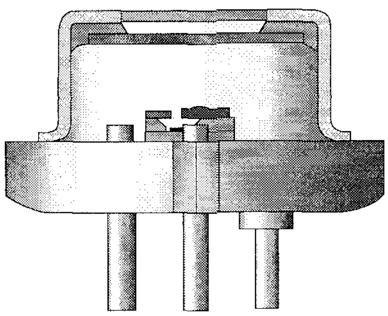


Figure 5. TO-Can Laser with Hybrid Integrated Si-Submount

The essential product relevant performances and not at least the quality of this technology-concept are based on the very compact design of the mechanically critical components between laserchip and the sensitive lens fixation. As already mentioned the precise positioning and the mechanical stability of the lens in front of the laser chip is base for the reliability of the complete fiberoptic component. This stability is fully meeted by the micro-mechanical junctions and micro-optical components. The low tolerances between lens and laser in dimensions of lower than 0.1μm in the full temperature range from -40°C to +85°C are fulfilled by a high beam-symmetrical construction and most essentially, by the low and nearly equal expansion coefficients of the micromechanical components as silicon submount, glass-mirror prism and silicon lens. But not only the very stable materials guarantee the needed opto-mechanical stability, but also the junctions between the constructive elements as the laser-silicon-submount, prism-silicon-submount and lens-prism-compound meet this stability.

We could solve the technical problem of highest alignment precision in combination with highly stable and durable fixation in using thin layers (< 3μm) of hard-solder (AuSn) with a contact-free semiconductor-power-laser heat source for solder-melting. The junction glass-prism to silicon is performed by the highly reliable and stable anodic bonding process in the preparation stage of the submount. The complete manufacturing process will be shown in the next paragraph.

The here shown micromechanical submount technology shown on the laserdiode assembling is only one example for the application of this technology for other fiberoptic components. A further realized application is the assembling of surface-sensitive photo-diodes or surface emitting infrared-diodes with hybrid integrated silicon micro-lenses. The construction is shown in Fig.6. In the common design for the photo- and ired-diode (which needs the same optics in opposite directions), the micro-optical silicon-lens is fixed on two glass bars, which have here only mechanical functions.

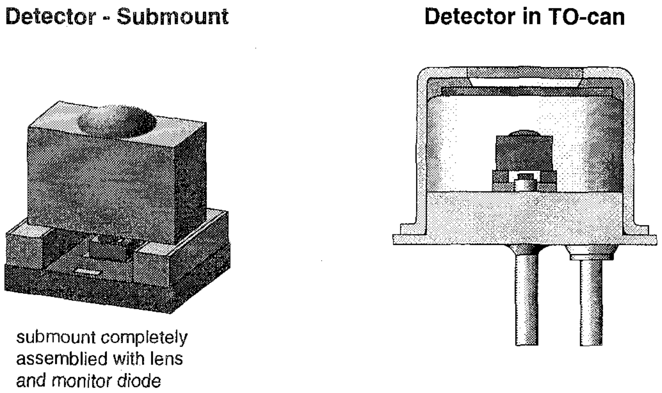


Figure 6. Detector Chip on Si-Submount with Lens and TO-Can

The microsystem-technological principle allows also here the essential step of production of the complete chip-lens-submount unit with neccessary testing procedures on wafer. In the following we will show the manufacturing procedure for the hybrid integrated submount components.

Waferprocesses for Microsystems

Beside the already mentioned advantages of the wafer-processes, the evidently largest advantage is the assembling of the individual submount- or device-units in a defined order from start to the end of the manufacturing process, including all neccessary and possible measurement steps. This gives the enormous possibility to identify at every production step every individual device per software in the shortest period of time. This is neccessary as far as the individual devices have individual parameters and performances.

The manufacturing of the microsytems, as well as the hybrid integrated laser-module as the chip-lens assembling of photodiode and IRED starts on the silicon-wafer base. As already mentioned we can apply in fabrication of silicon substrates the fully established semiconductor technology up to 6inch. The manufacturing process will be shown on the example of the laser-module submount. In Fig. 7 the starting wafer is shown in a sectional representation. The wafer diameter is here for example 5 inch.

The glass-prisms, which are lateron needed for reflecting the laserbeam 90deg to the wafer plane are manufactured out of a expansion adapted boron-silicat glass plate by cutting the glass plate in bars, followed by grinding polishing and coating the both side 45deg relecting surfaces. The attchement to the silicon submount wafer is done by a common anodic bonding process of all the glass prism bars covering the complete silicon wafer.

The die-attach and lead metallisation circuitry for the individual submounts are already preparated.

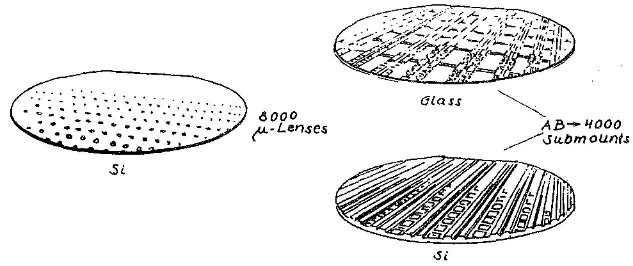


Figure 7. Si- and Glass-Wafers for Submount Assembling

After pre-cutting only the glass-bars the individual submounts are separated but fixed in the wafercompound on the wafer. In the next stage the laserchips are die-bonded on the metallized bond area between the two 45deg prisms.

This completely new micromecanical assembling process with using a AuSn-solder-layer for laser attachement could be realized with the application of an adapted semiconductor power laser heat source. As far as the pick and place process of the laser chip from a blue-tape carrier to the silicon wafer is an established semiconductor manufacturing process, the geometrical precision of the laser attachment and not at least the partial heating of the laser bonding region was no standard and could be successfully developed for serial production. First after this step the complete wafer process for laser module production was possible.

The power for soldering is provideed by a module of several single packaged high power laser arrayas, which are able to couple some watts of a 880nm-light-power into glass-fibres. This power source provides so a geometry- and time-controlled power intensity. The overall-program of the automatic die-attachment process controls so the attachment of laser-chips on about 4000 positions of individual submounts.

The metallization-design on submount enables an individual wire-bonding of each laser on submount and each submount to a stripe lead to the wafer end. This means that after die- and wire-bonding of the chips on the complete wafer the 4000 lasers are prepared for opto-electrical burn in and measurement. Fig.8 shows a sectional view of the wafer with bonded laser-chips prepared for burn-in.

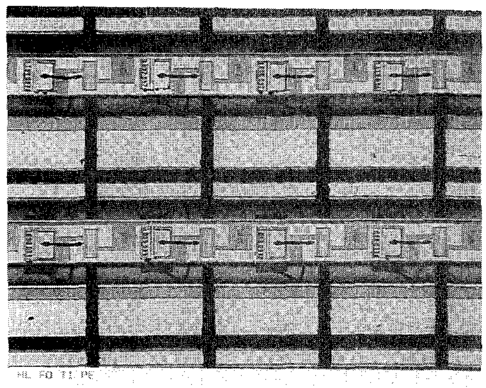


Figure 8. Bonded Laserdiodes on Si-Submount Wafer

In this view we see in the mid of the submount-chip the bonded laser diode with its p-contact bond to the metallization-leads. On both sides of the laser chip we see on the 45deg mirrors of the prisms the reflected front and rear side laser-mirror facets with the reflected figure of the bond wire. This figure gives a good idea of the upwards, perpendicular to the wafer plane, directed emission of the lasers. This perpendicular transformed laser emission enables the wafer-burn in and wafer testing procedures.

The wafer probing delivers a complete map of the individual lasers with essential individual data for further production steps. The following processes are the die- and wire-bonding processes of monitor diode and the lens alignment and fixation. Also these are wafer-production steps. The monitor bonding is, due to relaxed positioning tolerances, nearly a standard semiconductor assembling process. Although assisted with our light-power heat source, the lens alignment and fixation are more difficult. To realize the demanded optical beam of the emitted light, the optical parameters as laser-lens distance and lens focal length have to be determined.

As already mentioned in introduction, for the lenses of the one lens coupling system with lens inside package (for wavelengths from 1,3µm up to 1,55µm) silicon is a possible optical material. Our developments made it possible to use a dry-etching process for production lens-segments on a silicon-chips (this means a plan convex silicon lens) with the neccessary optical surface quality .This gives on a 4 inch silicon-wafer about 14000 individual lenses in this special dimension. Fig.9 shows in a photograph a section of such a microlens-wafer.

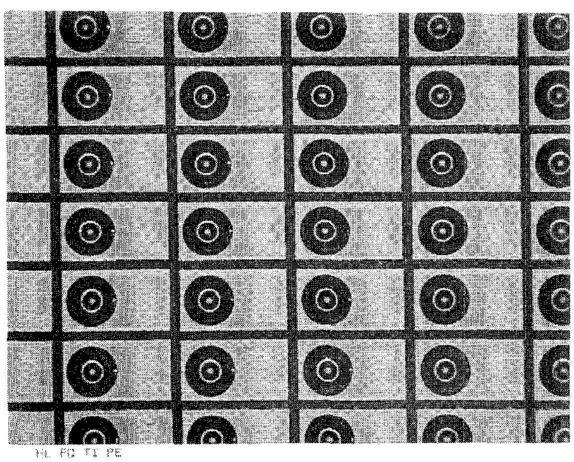


Figure 9. Microlens Wafer

The optical parameters, primarily the focal-length of the individual lenses are characterized automatically by an image processing system in reflection or transmission from the individual lenses. This system provides after measuring a complete map of the essential lens-data of the complete wafer.

These maps of characteristic data then guide the full automatic wafer to wafer manufacturing process of lens alignment and fixation. This complete process from identifying laser-submount chip to fixing the lens by light power soldering is full automatically performed by a new developed "rotating head" bonding machine". Cycle times of less than 10 seconds for the complete lens-alignment and fixation show evidently the high volume ability of these processes. As this process is designed to be in the time range of a standard semiconductor bonding process, it allows the high volume ability; in contradiction to the former manually performed lens alignment process of some minutes.

The previous descripition shows the most complicated wafer manufacturing process of the laser-submount module. In reasons of completeness it should be mentioned that also the system is able to produce the more simpler devices as ired- or photodiode-lens-submount units on wafer with shorter cycle times. The principle of the processflow on wafer for the example of photodiode with lens can be seen in Fig.10. Here we can follow the micro-mechanical process from wafer over the lens-supporting bars to the complete wafer unit with submount, bonded chip, and aligned lens. Also these units are burned and probed on wafer before assembling to TO-can.

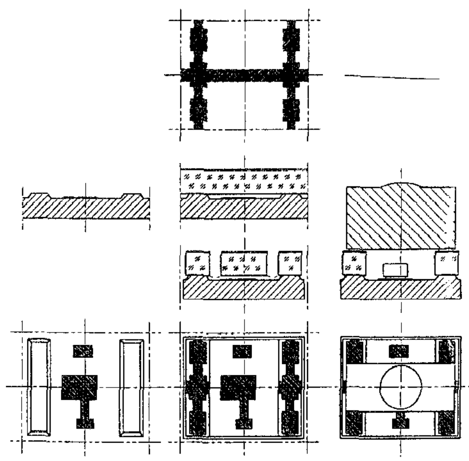


Figure 10. Submount-Assembling-Process Photodiode

Fiberoptic Device Family on the Base of Micro-Mechanical Subcomponents

Our intention was to integrate as much functions as possible into the hybrid integrated subcomponents and to test essential functions in a early stage of production not only to reduce yield losses, but also to increase the production-speed of the individual manufacturing steps (neccessary for a low cost high volume production). To provide for applications into fiberoptic transmission systems a robust device, which is able to withstand the usual environmental conditions (specified in the Bell-Core spec.) the assembling in a hermetically sealed TO-can is used. This device itself creates the subcomponent of higher order assembling units of fiberoptic modules. This differs not from standard microelectronic devices. In the application of components to fiberoptic transmission lines however, the not simple performance of these devices is the adaption to the glass-fiber, in much cases of application with optical dimensions only of some microns. Our applied micro-optic design fulfils all these demands in a optimized manner in the TO-can subcomponent [4].

Fig. 11 shows the application of the types of TO-can subcomponents to the different types of modules for fiber-optics. Generally there are two different coupling principles to the fiber. One of them is the one-lens-coupling system for unidirectional transmission, the other is the dual-lens-coupling system in bi-directional transmission to singlmode fiber (SMF).

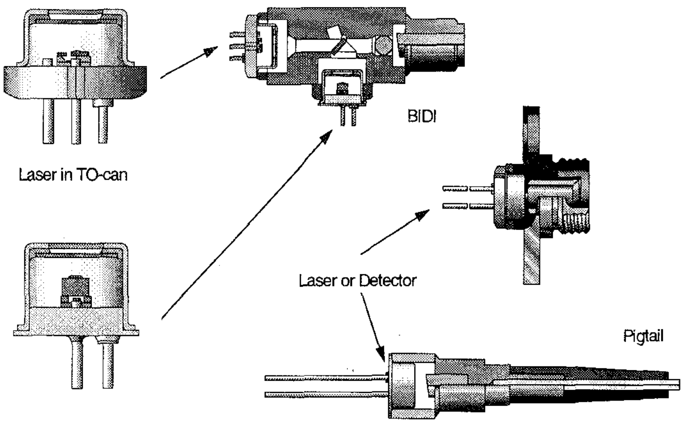


Figure 11. Construction Set of TO-Subcomponents to Fiberoptic Modules

In the one-lens-system, only the integrated silicon lens on submount allows differential efficiencies of the coupled power up to 120µW/mA specially for pigtail-lasers with adapted fiber-end geometry In application to receptacle components, this means the devices with detachable fibers direct on the component the coupling performance may be reduced due to non optimized standard plane connector ends
The second application is in the two lens optical system for bi-directional modules (BIDI) with the TO-can subcomponent of laser and detector The two lens system realizes a free optical beam-path for implementation the neccessary beam-splitter or wavelength-division-multiplexing (WDM) -filter between TO-cans and fiber for wavelength-independent or -dependent application. These BIDI-modules so are suitable for semi-duplex, wavelength independent transmission and full-duplex wavelength dependent transmission on one single fiber. The system applications and particuar advantages of these modules are shown in part II.

Reliability of Fiberoptic Modules with Micromechanic Subcomponents

One of the essential reasons for application of micro-mechanics in the fiberoptic components was to establish the reliability of the complete devices under all environmental conditions of application. To do a most extensive test of the module performances under the Bell-Core testconditions we selected the BIDI-Module (as shown in Fig. 11) as representative. The results can provide then the mechanically stability of all components and subcomponents. This module represents the most difficult optics of highest precision, mainly of the laser lens subcomponent of +/-0.1µm as also of the micro-mechanical and micro-optical subcomponents. Nevertheless, to guarantee the overall-stability of the complete module with coupled SMF, the next critical junction of the fiber to the module, with possible tolerances of +/-1µm, fixed by laser-welding on the solid module housing, is of a high significance The Bell-Core adapted testconditions and the results are shown in Tab. 1 [5].

The complete measurement diagram of coupled power after the most loaded test, the slow (about 1h) temperature cycling from -40°C to +85°C over some thousands of cycles is shown in Fig.12. Here it can be seen, that up to 7000 cycles there is no change in coupled power of more than +/- 10%. This impressive result becames more evident, if we look at the Bell-Core spec which demands the prove of this stability only up to 500 cycles and observation of the behaviour of stability up to 1000 of cycles.

HEADING	TEST	REFERENCE	CONDITIONS	SAMPLING			Siemens Actual Conditions	Actual SS	Failure	Device Type
				LTPD	SS	C				
Endurance	Accelerated Aging (High Temp.)	(R) -453 Section 5.18	85°C;rated power ≥5,000hrs ≥10,000hrs	- -	25 10	- -	-	-	-	-
	High Temp. Storage	---	max. storage T; ≥2,000hrs.	20	11	0	85°C 2000hrs	11	0	BIDI
	Low Temp. Storage	---	min storage T; ≥2,000hrs.	20	11	0	-40°C/2000hrs	11	0	BIDI
	Temp. Cycling	Section 5.20	-40°C to +85°C 400x pass/fail 500x for info. 500x pass/fail 1,000x for info.	20 - 20	11 11 11 11	0 - 0 -	-40°C/+85°C 5000x & -40°C/+85°C 1000x (requal.)	11 11	0 0	BIDI BIDI
	Damp Heat (if using epoxy)	MIL-STD-202 Method 103 or IEC 68-2-3	40°C/95%RH 56 days;or 85°C/ 85%RH 2,000hrs	20	11	0	40°C/93%r.H. 56 days	11	0	BIDI
	Cyclic Moist. Resistance	Sec. 5.23	---	20	11	0	-	-	-	-
Special Tests	Internal Moisture	MIL-STD-883 Method 1018	≤ 5,000ppm water vapor	20	11	0	TO cans: check at welding			
	Flammability	TR357:Sec.4.4 .2.5		-	-	-	supplier spec.			
	ESD Thresh.	Section 5.22		-	6	-	HBM	6	-	TO cans

BIDI

Table 1. Bell-Core Test on BIDI-Modules.

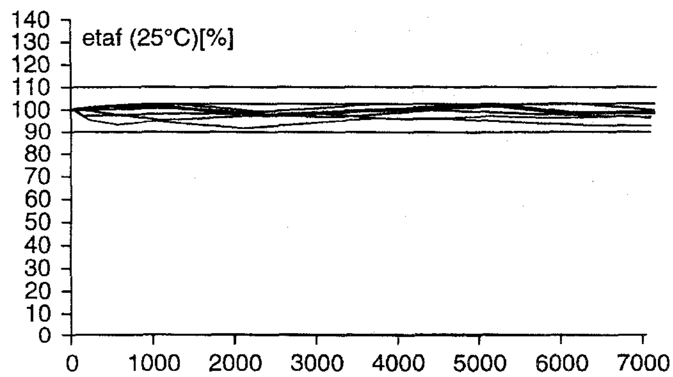


Figure 12. Cycle Tests on BIDI-Modules.

These outstanding results of reliability tests of our fiberoptic components were not at least possible with the extensive application of the microsystemtechnique in combination with a highly symmetrical design and the use of most solid anorganic materials and junctions in the fiberoptic components.

The results show also that the right combination of low cost microsystemtechnical processes with adapted procedures, and materials allows a low cost production high volume production of devices with excellent quality.

Recent Developments

Enhanced by the encouraging results of application of micro-systemtechniques our new investigations and developments concentrated on further hybrid integration of opto-electrical functions on the laser-submount module. In the last developments we could realize a bi-directional module, which integrates the both bi-directional functions on a adapted lasermodule submount in combination with a photodiode chip. This means we could integrate the complete BIDI-module in one TO-can. This module type is named TO-BIDI. [...]

The approach for the design of this module was to use as much of the successful and well-tried technology as possible, not only to save efforts of neccessary but expensive qualification tests but also to realize a low cost design. In this sense we used the reliable silicon-laser-submount module not only as emission unit but also as part of the detector unit.

This means, in the case of emission the unit works as a standard laser module. In the case of detection with light power out of the same fiber (BIDI-principle) the same lens, fixed on glass-prism focuses the incoming fiber power onto the detector-diode. This detector diode is placed below the backside of silicon submount chip and is reached by the incoming power (for example 1300nm) which penetrates the glass prism, coated with a 45deg WDM-filter and the optical transmissible silicon submount. Fig.13 shows the general design and the optical path.

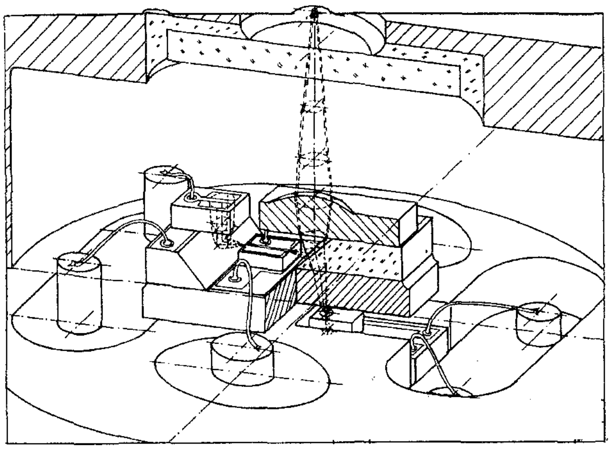


Figure 13. TO-BIDI Design

The micro-optical and mechanical design of the TO-BIDI fit completely in the standard fiberoptic component design. This means it is able to adapt to the standard fiber accesses of pigtail- or receptacle-modules.

II Applications for Telecom and DatacomTransmission Systems

More than 20 years ago starting in the field of long haul lines optical transmission has been introduced as standard transmission technique. Today we have a lot of applications for Telecom- and Datacom-Lines The most technical problems are solved. Therefore miniaturisation and cost reduction are in the focus of further developments in order to compete with copper lines [6].

High speed datacom lines up to 200 Mbit/s are working with IRED (1300nm light emitting diode) and systems with lasers for higher speeds are under development now. On the field of datacom lines enormous cost reductions were able with the shown micro-technologies without reducing performance and reliability. On the field of optical transmission for long haul lines the datarates are increased also. These systems need DFB laser diodes, where the introduction of uncooled modules enables cost reduction.
Compared with Telecom- and Datacom-Application the introduction of optical transmission in the access network is now starting. Due to the high volume this is a very important field for the application of low cost components.

The datarate for new services is growing continuously and the limits for the existing copper lines are evident. "Fibre to the Home" needs medium datarates (up to 155 Mbit/s) and medium length (up to 10 km).

The optical subscriber line has to compete with copper lines. There are two low-cost approaches in the bit transport system for getting competitive with the existing copper plants.

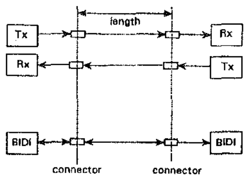
- The first approach is passive optical network (PON)
- The second approach is bi-directional optical transmission

The structure of the optical network in the subscriber loop has changed in the last years. In the beginning was planned to realize a star-network around the local exchange with point to point connections. Than the passive optical network (PON) architecture was introduced. The splitting point should be realised with passive power splitter. The passive star is an improved approach. Keywords for this development were: laser sharing, fibre sharing.

A single transmitter/receiver module can communicate with many optical network units (ONU). This set-up results in hardware savings by eliminating numerous transmitter/ receiver modules in the remote terminal. Part of this savings is compensated by the cost of the splitter. The use of a passive star configuration divides the available optical power among all the optical network units connected to the splitter. This division may or may not be a problem, depending on the specifics of the implementation. For example, with the optical power split among 16 or more optical network units and a maximum distance between central office and ONUs of 20 km a high power budget (order of magnitude 30 dB) is needed.

The second step for cost reduction is to use only one fibre for bi-directional optical transmission. A simple dual-fibre unidirectional communication link consists of two trans-mitters (each containing a laser), two optical fibres and two receivers (each containing a photodetector). These optical-electronic components usually come in four packages with individual connectors, or in transceivers with dual connectors or pigtails. A simple single-fibre bidirectional link also requires two transmitters with two lasers, and two photodetectors for two receivers. However it requires only one fibre and only two transceiver assemblies, which significantly reduces materials and labour costs. These figures of comparison are shown in Fig. 14.

Cost Comparison two Fibers versus one Fiber Transmission Systems



System	Fibre	Connector	Tx	Rx	Splitter
Two	2	4	2	2	-
One	1	2	2	2	2

Additional advantages of the one fiber system
- Installation cost
- Space consumption for connectors and pigtails

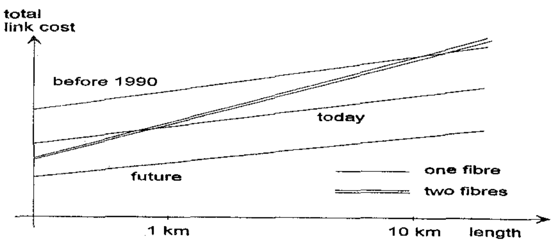
Figure 14. Comparison of One-Fiber and Two-Fiber Systems

In the beginning these savings were partially compensated by the need for a fibre splitter at each end of the link in a discrete solution or by the higher effort for the first modules for bidirectional optical transmission with built in splitters.

Cost Comparison between Two- and One-Fibre Systems

Due to the cost for the module with beam splitter the bidirectional link starts with higher cost today. The costs for a two fibre increases more rapid due to the fibre cost. A diagram with total link costs against the fiber length is shown in Fig.15.

Cost Comparison two Fibers versus one Fiber Transmission Systems



Exact Cost Comparison difficult, depends on
- Installation and fiber cost
- Connector and pigtail cost
- Rx, Tx and BIDI cost

Figure 15. Diagram Fibrelink Costs versus Fiber-Length for One- and Two-Fiber Systems

Important for a cost comparison is the crossing point of the two lines. In the beginning of bidirectional optical transmission this point was located at several km. Today the bidirectional trans-mission is already attractive at length shorter than 1 km.

In the near future modules for bi-directional optical transmission will be,as upper mentioned, realized in one TO-can. They need only one receptacle or pigtail and only one connector. Therefore in future bi-directional optical transmission on one fiber will be attractive for all length.

Wavelength Allocation and Upgradeability

Bi-directional optical transmission is possible as well by using one wavelength for both directions or by using two optical wavelengths in wavelength division multiplexing (WDM).

In the first step of bi-directional transmission on one fibre, the 1300/1550nm-WDM-system is established. Hundred nm for each laser and 120nm for the filter allows it to design the modules as low cost components. For 1300/1550nm wavelength selection in WDM, a dielectric optical filter is used and losses in the beam separation can be minimised. To improve the selectivity of the filters and also the crosstalk attenuation, the PIN-photodiode is provided with an additional blocking filter. In Fig.16 the wavelength allocation is shown in graphic representation.

Wavelength Allocation for the WDM BIDI

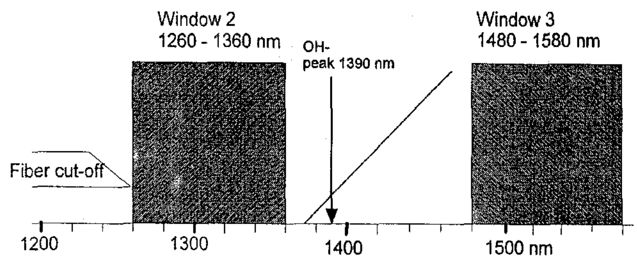


Figure 16. Wavelength Allocation for a One-Fibre WDM-System

Systems using both windows (WDM 1300/1550 nm) are therefore very robust concerning reflections and the wavelength tolerances. If both windows (1300nm and 1550 nm) are occupied an upgrade with a third wavelength is only possible with major changes. Sometimes such arguments are used against this wavelength allocation. Therefore in a next step, bi-directional optical transmission in one window will be realized. The needed optical filters are available. DFB Laser diodes with the needed accuracy of the optical frequency are under investigation.

In the one wavelength module, a 3 dB beam splitter is used for separating the transmitted and received optical signals. Here the maximum power and the responsivity are reduced by the beam splitter. It is not possible to combine the beam splitting with any selectivity. Therefore the greatest disadvantage of this type of modules is the sensitivity against optical crosstalk. Using the lower sensitive half-duplex transmission, the transmission capacity is reduced. Working in full duplex mode the optical crosstalk is the limit for power budget.

Definition of Modules for Different Applications

In order to offer optimised modules for the different system architectures we propose three module-concepts.

- For a PON with high splitting ratio WDM, the using of two optical wavelengths in both windows (1300 nm and 1550 nm) is the best choice.
- If half-duplex transmission is allowed bi-directional transmission with one optical wavelength is possible and high power budgets can be achieved also.
- For new systems with active splitter low power budget and low cost modules are under development. In order to minimise the effort on the electrical side these modules enable full duplex transmission.

These three solutions are summarised in the following Table 2.

Power budget	Transmission	Module
Very high	Full-duplex	WDM, Standard Case
High	Half-duplex	One Wavelength 3 dB Splitter, Standard Case
Low	Full-duplex	Very low cost, Redesign small case under development

Table 2. Bi-directional Transmission Systems

Conclusion

The previous descriptions show, that is was possible to establish methods of the very young microsystem-technology in industrial high volume production processes. The exploitation of this new technology was the right approach to solve the difficult task of realizing a big scale production of a product with very low mechanical tolerances.
Furthermore it was possible to establish also the highest standard of reliability for this performances with lowest production- and component- costs. But the shown exploitations of the microsystem-technique for efficient fabrication of TO-can -lasers and -detectors are only the beginning. New developments could show the possibilities of a efficient hybrid integration of mechanical, optical and electrical functions as for example bi-directional modules in a single TO-can.

We are aware also on the research and development work on a full integration of these bidirectional functions on chip with a common substrate material for all functions [.7.] From our point of view the technology of full integration will get its breaktrough if the functional yield of the single components is high enough to spent the up to now expensive semiconductor material (e.g. InP) only as a supporting substrate.

The challenge is to realize now the breaktrough of the fiber-optic transmission against copper . This is possible today from our point of view with fiberoptic components, fabricated with the extended use of microsystem-techniques on wafer.

For the system-applications the techniques described here allows to find the optimum between performance and cost for these applications. Using the bi-directional transmission the effort for the bit transport can be reduced near or even below the level of copper lines. Therefore in the last years the for example the German Telekom has installed a lot of subscriber lines using modules for bi-directional optical transmission [8].

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