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CONSTRUCTION OF AN AUTOMATED FIBER PIGTAILING MACHINE

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Introduction

At present, the high cost of optoelectronic (OE) devices is caused in part by the labor-intensive processes involved with packaging. Automating the packaging processes should result in a significant cost reduction. One of the most labor-intensive steps is aligning and attaching the fiber to the OE device, the so-called pigtailing process. Therefore, the goal of this 2-year ARPA-funded project is to design and build 3 low-cost machines to perform sub-micron alignments and attachments of single-mode fibers to different OE devices. These Automated Fiber Pigtailing Machines (AFPMs) are intended to be compatible with a manufacturing environment and have a modular design for standardization of parts and machine vision for maximum flexibility. This work is a collaboration among Uniphase Telecommunications Products (formerly United Technologies Photonics, UTP), Ortel, Newport/Klinger, the Massachusetts Institute of Technology Manufacturing Institute (MIT), and Lawrence Livermore National Laboratory (LLNL). UTP and Ortel are the industrial partners for whom two of the AFPMs are being built. MIT and LLNL make up the design and assembly team of the project, while Newport/Klinger is a potential manufacturer of the AFPM and provides guidance to ensure that the design of the AFPM is marketable and compatible with a manufacturing environment. The AFPM for UTP will pigtail LiNbO₃ waveguide devices and the AFPM for Ortel will pigtail photodiodes. Both of these machines will contain proprietary information, so the third AFPM, to reside at LLNL, will pigtail a non-proprietary waveguide device for demonstrations to US industry.

AFPM Concepts

The AFPM (Figure 1) is designed to be low-cost (<\$150K), modular, flexible, and compatible with a manufacturing environment. The performance goals of the AFPM are to perform each pigtailing operation in less than 3 minutes (including the epoxy curing time) and to operate unattended for up to 1 hour. During the alignment operation, the OE device is held fixed while the ends of the fibers are moved by the high-precision stages. These machines incorporate a 2-step procedure to perform sub-micron alignments. The first step uses computer vision to align the fiber sufficiently close (few microns) to the OE device to couple light between the fiber and the device; the second step then achieves the sub-micron alignment by maximizing the light throughput. The overall design of the AFPM was carefully considered to minimize the requirements for high-precision machining tolerances; this greatly reduced the cost of building the AFPM. Considerable effort was put into the parts handling scheme which allows the AFPM to operate unattended for significant amounts of time. The modular nature of the AFPM means that each machine may be easily customized for a particular application. For this project, a basic set of modules was designed to build prototype AFPMs which can pigtail devices with 3 very different geometries including a photodiode and two different types of waveguide devices; a different set of the same modules would allow laser diodes to be pigtailed, for example.

Performance Criteria

LLNL and MIT worked closely with UTP and Ortel to ensure that the AFPM would satisfy all requirements for both types of OE devices. The choice of a LiNbO₃ waveguide device by UTP and a

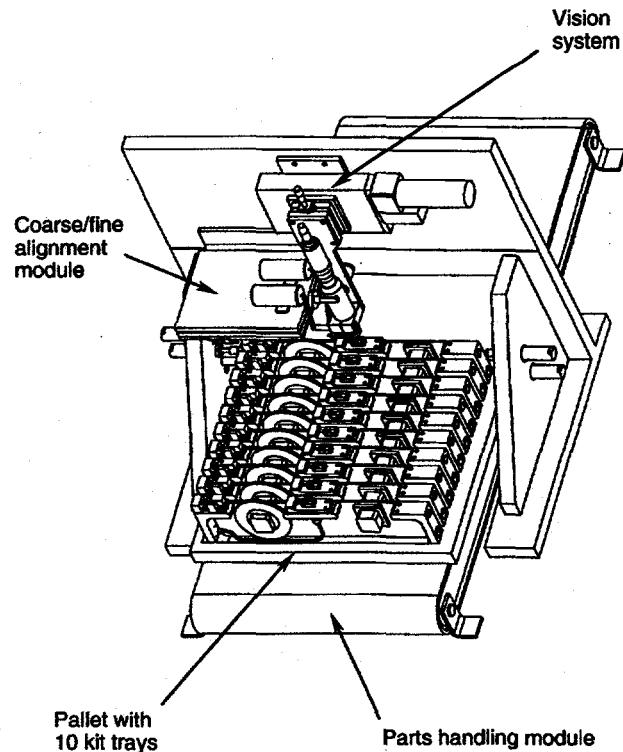


Figure 1. The Ortel AFPM has one high-precision stage mounted on the left side of the frame.

photodiode by Ortel provided a wide variety of criteria for the AFPM to satisfy. The UTP waveguide device operating in single mode requires sub-micron resolution, especially in the lateral dimensions, while the alignment tolerances for the Ortel photodiode are an order of magnitude less severe. On the other hand, the photodiode alignment and attachment must occur inside a 14-pin DIP package, which is a very restrictive geometry, while the waveguide device has much more open space available for the AFPM operation. Both devices use epoxy attachment but the amounts used in each case are different by over 2 orders of magnitude. For the third AFPM, LLNL chose a simple waveguide device which has requirements common to both devices of the industrial partners. Therefore, the third AFPM requires sub-micron alignment resolution similar to that of the UTP AFPM but uses an epoxy dispensing scheme more closely resembling that of the Ortel AFPM.

AFPM Design

The AFPM has a modular design. The various modules are mounted on a frame which allows a relatively high (few mils) precision placement of the modules with respect to each other; which modules are chosen depends upon the type of OE device to be pigtailed. For example, a device such as a photodiode has only one fiber so the AFPM would require only 1 high-precision stage mounted on the left side of the frame as shown in Figure 1. A waveguide device needs fibers pigtailed to each end so the AFPM would require 2 high-precision stages; in Figure 1, an identical high precision stage would be mounted on the right side of the frame. The sub-micron alignment is performed using active feedback; that

is, the light coupled to the OE device is maximized. Therefore, a source coupling module can be mounted on the left side of the AFPM and a photodetector module can be mounted on the right side of the AFPM to provide the light and the monitoring of the light for the active feedback. In our two examples, an AFPM pigtailing a photodiode as shown in Figure 1 would require only a source coupling module because the photodiode itself would monitor the maximizing signal. The waveguide device would require both a source coupling module and a detector module. If the AFPM were chosen to pigtail laser diodes, for example, the AFPM would require one high-precision stage mounted on the right side of the frame and only a detector module; the laser diode itself would provide the light for the active feedback. In all cases, a vision system would be mounted directly over the OE device to provide the information required to initially locate the fiber and the target area of the OE device. A conveyor system is provided to deliver the OE devices to the alignment stages and vision system. A description of several modules is given in the following subsections.

High-precision Stages

The high-precision stages were designed and built by MIT after extensive discussions with UTP and Ortel regarding the required resolution and range. The required resolution was determined by the mode size of the UTP waveguide device operating at 830 nm and the corresponding single-mode fiber to be pigtailed. The resolution of the stages needs to be a small fraction of the waveguide dimensions to ensure high coupling efficiencies. For the AFPMs, the chosen resolutions for the stages were 0.1 micron in the lateral dimensions and 0.5 micron in the longitudinal dimension. The range of the stages was determined by the working volume required by the AFPM to access the interior of the 14-pin DIP package of the Ortel photodiode; for this project, the range of the high-precision stages was chosen to be 25 mm in each of three translation directions. The issue of whether to include fiber roll in the AFPM created considerable discussion. Ultimately, roll was not included for this project once satisfactory mechanical fixturing was designed to accommodate this degree of freedom.

Vision Module

The vision system greatly reduces mechanical fixturing constraints by requiring the critical components to be positioned only within the field of view of the camera. The field of view for all 3 AFPMs is approximately 1 mm by 1.2 mm with approximately 2 micron resolution. Achieving mechanical precisions sufficient to locate the OE device and the ends of the fibers within this field of view is fairly straightforward. Object-recognition algorithms written by LLNL allow the AFPM to determine the initial locations of the OE device and the fiber; this image analysis takes between 1 second to 6 seconds, depending upon the complexity of the image. The 2-micron resolution of the vision system allows the fiber to be

moved to within a few microns of the desired initial position. This is sufficiently accurate to ensure that some coupling of light between the OE device and the fiber will occur. At this point, the AFPM switches to active feedback to perform the sub-micron alignment, that is, the AFPM performs a series of peak-finding motions until the coupling efficiency is maximized. An additional advantage of the vision system is that it increases the flexibility of the AFPM by allowing different devices to be pigtailed with only software changes and minor mechanical changes.

Parts Handling

One of the original design criteria for the AFPM was that it should operate unattended for at least an hour; this implies that at least 20 pigtails will be performed without operator intervention. The issue of parts handling and feeding becomes important for an automated system compatible with a manufacturing environment. Many aspects of the electronics industry are fully automated in terms of feeding parts to the assembly stage, so the technology is well developed. For this project, however, a parts handling scheme was developed which relies upon the operator to load the OE device and the fibers into a tray, the so-called kit tray (Figure 2). A set of six loaded kit trays is placed onto a pallet by the operator who then places the pallet onto the conveyor system of the AFPM. The conveyor system may be chosen to have any length necessary to allow the desired time of unattended operation.

The kit trays shown in Figure 2 are designed for easy placement of the OE device and the fibers with sufficient accuracy to allow alignment by the AFPM. The overall design of the kit tray is standard for all applications. The tray body is cast from hard plastic which allows 25 micron repeatability of the placement of the OE device with respect to the vision system from tray to tray. The kit tray can hold up to four spools of fiber depending upon the type of OE device to be pigtailed. Unfortunately, every OE device has a different geometry so no standardization of the kit tray was possible for the fixture to hold the device. The kit tray body is designed to accommodate a device cartridge which fits onto the top of the kit tray; the device cartridge is one of only two AFPM components which must be custom designed for each OE device application (the other custom designed component is the vacuum chuck which moves the fiber during the alignment procedure).

Summary

Clearly, this 1st generation AFPM cannot accommodate all possible variations of OE device pigtailing geometries. For example, all applications for this project use epoxy to attach the fibers, so no applications using solder or laser welding have been considered. Also, the stages to manipulate the fibers provide only 3 axes of translation, so no rotational degrees of freedom are available, including the very important roll axis for polarization-dependent applications (for this project, roll is accommodated either

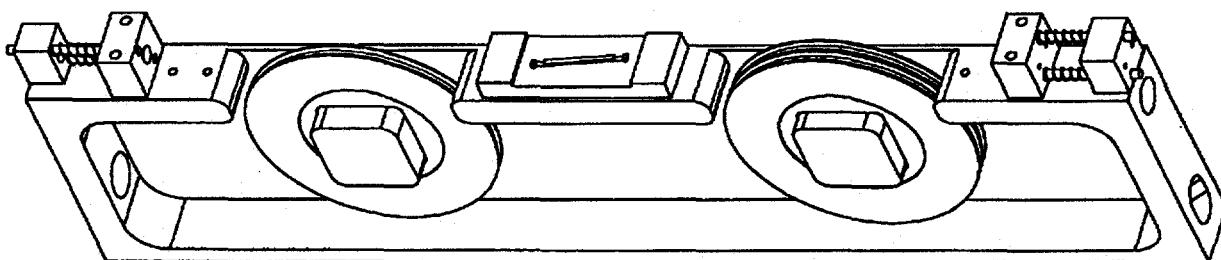


Figure 2. The kit tray measures 15" long by 3.5" high by 1" thick. The tray body is standard for all applications while only the device cartridge in the center is customized for each OE device. The fiber spools can hold at least 2 meters of fiber.

by mechanical fixturing or by manually loading the kit tray with the fibers in the proper orientation). Nevertheless, this project has enabled many of the critical technologies to perform automated sub-micron fiber pigtailing compatible with a low-cost manufacturing environment. These technologies include low-cost high-precision stages, computer vision to replace the labor-intensive coarse alignment, and many details of parts handling and feeding. Subsequent generations of the AFPM may build upon the design concepts developed here to pigtail fibers to OE devices in more complicated geometries.

At this writing (December 1995), the 3 AFPMs have been mechanically and electrically assembled. All three machines are undergoing final testing and software development before delivery to the industrial partners. After incorporation of the machines into their manufacturing lines, the industrial partners will perform a short production run and evaluate the performance of the AFPMs.

Modifications will then be suggested and will be incorporated into the final design of the AFPM where possible. At the end of the project, LLNL will host the Final Design Review (FDR) to which representatives of US industry will be invited. At the FDR, the design of the AFPM will be discussed and a pigtailing demonstration will be performed using the non-proprietary AFPM to reside at LLNL.

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