Optical fiber switching device with active alignment

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ABSTRACT

The alignment of optical elements in a Micro-Opto-Electro-Mechanical System (MOEMS), is of prime importance in order to realize a reliable and low loss system. Fabrication errors or temperature changes deteriorate the alignment accuracy. These errors can be compensated with the aid of an active alignment system. The aim of the paper is to investigate an active system in order to align microlenses and fibers within a system.
A high lateral precision is required for single mode fiber injection, typically better than 1 μm. With the active alignment system we can correct a misalignment of $\pm$ 6 μm.

Keywords: Optical switch, Alignment, Fiber, Microlens.

1. INTRODUCTION

Micro-optical and micro-electro-mechanical technologies have been highlighted during the last few years. Thanks to their potential of batch processing and cheap replication, these technologies are merging to create a new and broader class of micro-opto-electro-mechanical (MOEM) devices.
New concepts of photonic networking are being developed to increase dramatically the data capacity of optical fiber communication networks. A prototype system based on the wavelength division multiplexing (WDM) principle is developed at the IBM Zürich Research Laboratory. It makes possible to transmit multiple data channels simultaneously at different wavelengths over a single fiber. Optical switches bring reconfigurability for transmitters and receivers as well as easy bypassing nodes by using just one redundant fiber (Fig. 1). Opto-mechanical switches will enhance the versatility of the prototype significantly.

Optical switches are an attractive alternative to electrical switches in electro-optical systems, because of their low weight and immunity to electromagnetic interference, and because they eliminate the need for optical-to-electrical and electrical-to-optical conversion at the switch. Some non integrated switches are already commercialised, but all use big mechanical systems for fiber positioning and are extremely expensive. Optical switches that utilize micromechanical switching elements are best suited for integration (low price mass production); they can provide high contrast, large bandwidth and have multiple wavelength compatibility. The aim of our work is to develop a fiber optical switch to be used in telecommunication ring networks.
The basic elements of such an optical switch are fibers, microlenses and mirrors or eventual gratings for deflecting the light. In order to have a reliable and low loss switch, the optical elements have to be aligned with a high accuracy. Two different approaches are mentioned in the current MOEMS literature[1]: passive alignment and active alignment of the components. The passive alignment is realized once, generally during the fabrication process. The active alignment process is more complicated as the adjustment of the optical elements is realized in real time, looking always for the best position. Nevertheless, active alignment helps to considerably reduce the system tolerances (fabrication errors, stability). This paper deals with an active system in order to align microlenses with respect to fibers. For that purpose, we investigated an XY-stage which holds all elements of the system. First, we describe briefly different configurations for optical switches.

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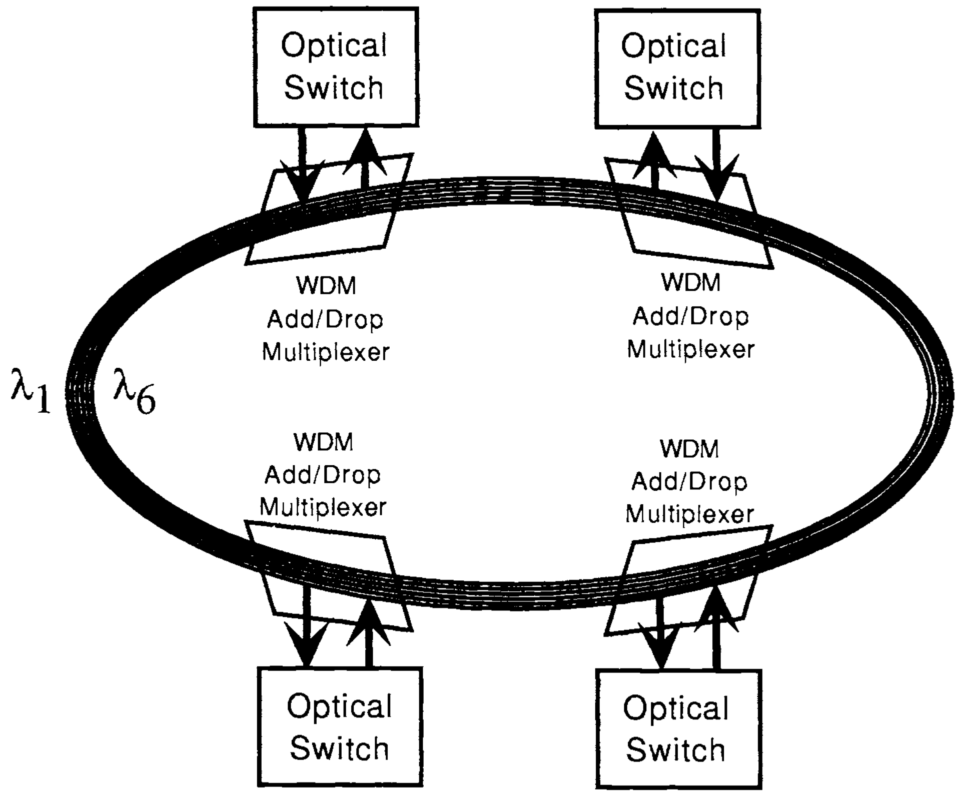

Figure 1. WDM ring network.

2. CONFIGURATIONS FOR OPTICAL SWITCHES

Different kinds of free space optical switch geometries have been considered (Fig. 2). These systems can work in reflection or in transmission. The reflective systems are in general more compact. Figure 2(a) shows a 1-to-1 imaging configuration which means that the fiber output is imaged onto the mirror. The light can now be redirected from the central fiber to the neighboring fibers by shifting the imaging lens. The system behaves differently, if the imaging is done by separated microlenses, see Fig. 2(b). There, we can deflect the light by rotating the mirror. The position of the image points on the fibers is only dependent on the position of the microlenses with respect to the fibers. Figure 2(c) shows a Fourier transform configuration which is more compact. The light can be redirected by shifting the lens, but also by rotating the mirror. Only one optical element is needed when using a concave reflective mirror, see Fig. 2(d). All these systems can also be built in transmission [Figs. 2(e) and (f)]. Instead of using mirrors, the light can be deflected by gratings. Note that gratings generate only discrete diffraction orders which limits the possibility for fine tuning of the direction.

In order to study the potential of an active alignment system, we choose a simple transmission setup as shown in Fig. 2(e).

3. EXPERIMENTAL SETUP

We realized the experiments at a wavelength of λ=633nm. Our system consists of a microlens placed between one input fiber and one output fiber. The distance between fiber and lens is twice the focal length (2f) in order to have a 1x1 imaging (Fig. 3). The fibers are single mode fibers with a core diameter of 5μm. The fibers are held in V-grooves with a small cylindrical magnet (Fig. 6). The microlens are fabricated by melting resist technology and transferred into quartz by plasma etching.[2] Their diameter is 245 μm. The focal length is f_1=410 μm (height h_1=41.5 μm). The quartz substrate is mounted on the XY-stage as shown in Fig. 6.

The XY-stage is realized in one steel block 10x20x28 mm^3 by wire electro-discharge machining (wire-EDM).[3] Figure

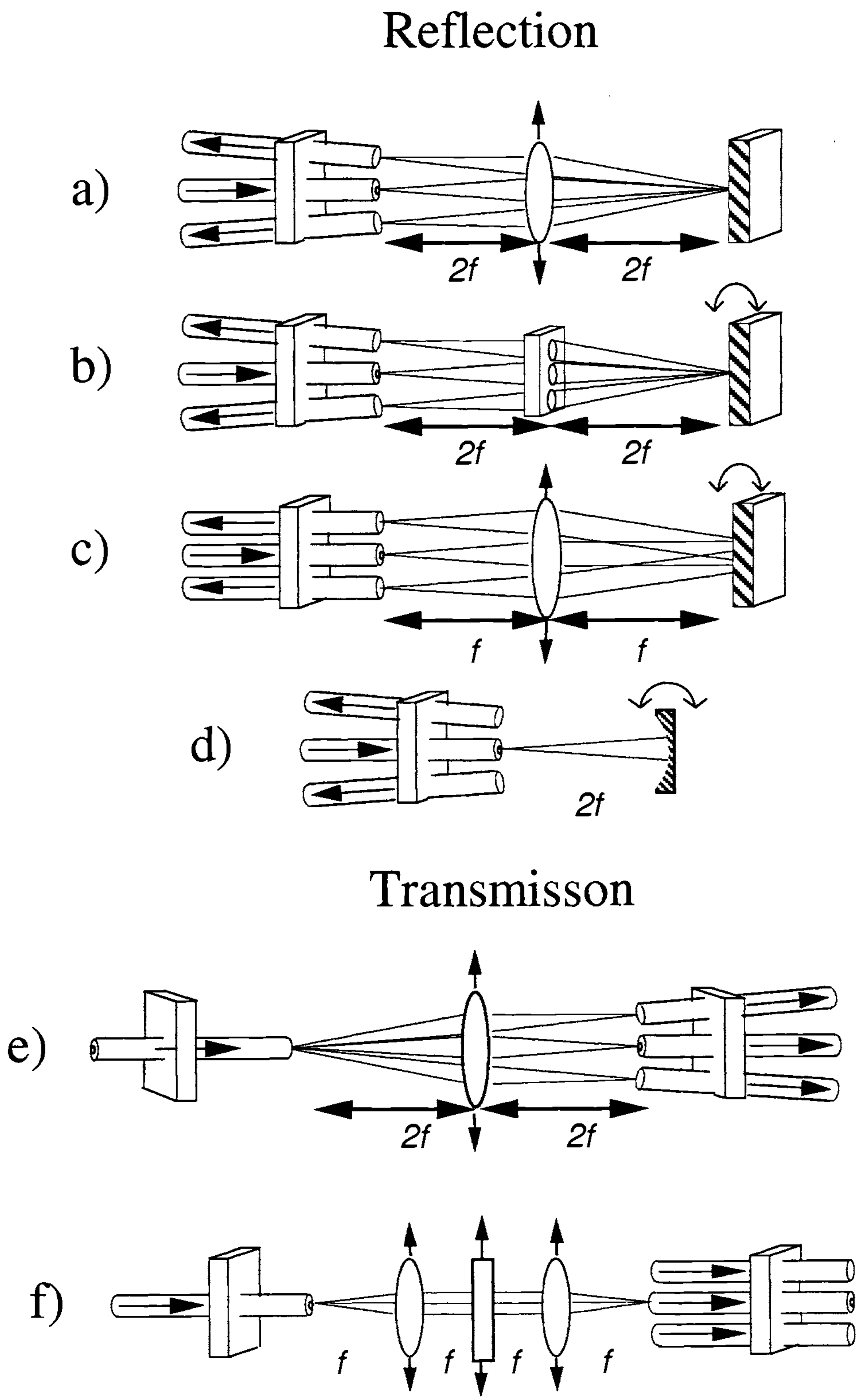

Figure 2. The different configurations of free space optical switches.

4 shows the stage with the flexible bearings. The bearings allow displacements of 100μm in the X and Y directions. The flexion is continuous and has a very good repeatability. Two piezo-electrical actuators move the flexible bearings of the stage in the vertical and lateral directions by 60 μm and 90μm, respectively. The fibers are mounted on a translation stage (Fig. 7) for the longitudinal adjustment along the optical axis which is realized manually. The feedback loop is based on a detection of the output signal and a correction of the x/y position of the lens using the two piezoelectric actuators (Fig. 5). The loop is computer controlled.

4. RESULTS

A high lateral precision is required for single mode fiber injection, typically better than 1 μm. The alignment along the optical axis is less critical. The initial signal threshold needed for the feedback loop is 280 times smaller than the output signal. This corresponds to a misalignment of 6μm of the lens. This means that in a switching configuration (Fig. 9), the lens as to be aligned (after a switch step) with an accuracy of $\pm$ 6μm. Otherwise, the feedback loop cannot lock onto the signal to optimize it. This limitation is mainly due to the detector and to the acquisition system and can be improved using a lock-in amplifier for the detection. Figure 8 shows the output signal during the adjustment process for two different initial positions. The time needed to reach the maximum signal is a few seconds. This time depends on the parameters taken for the regulation procedure and on the initial position of the lens. It can be shorten in improving the regulation procedure, which is relatively simple at the moment. Insertion losses are typically 30% after the fine positioning. The main losses are due to reflections at the interfaces and to the lens aperture.

5. CONCLUSIONS

We investigated an active alignment system to be used in a micro-opto-mechanical system. This system is self-aligning and therefore promising for a single mode fiber coupling. Without active alignment we would need an accuracy better than 1 μm. With the active alignment system we can correct a misalignment of $\pm$ 6 μm. The next step will be to extend the system to a 1x3 monomode fiber switch (Fig. 9).

ACKNOWLEDGEMENTS

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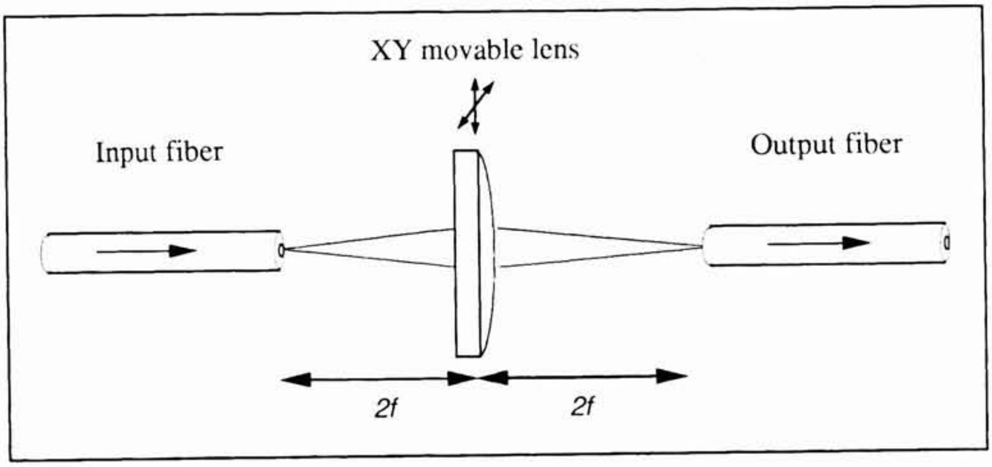

Figure 3. Setup of the coupling system. The lens can be shifted in x and y direction.

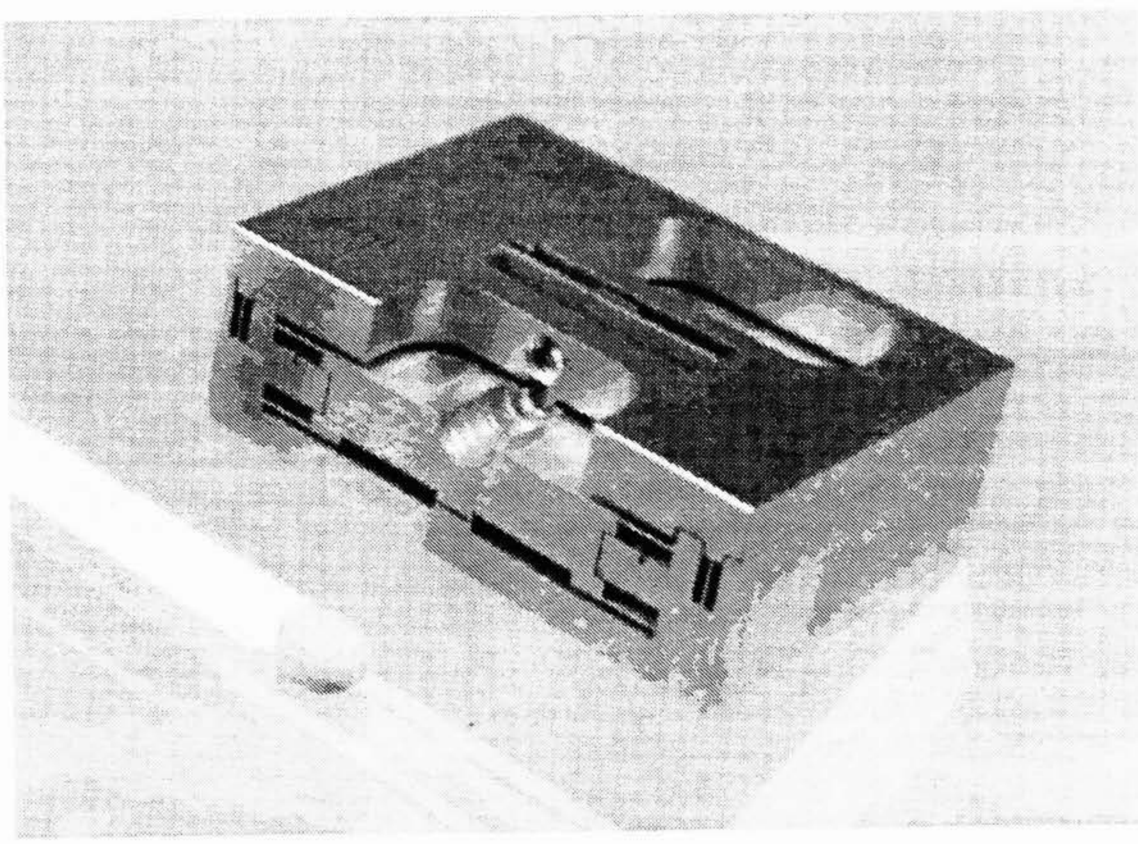

Figure 4. XY-stage fabricated by wire electro-discharge machining (wire-EDM).

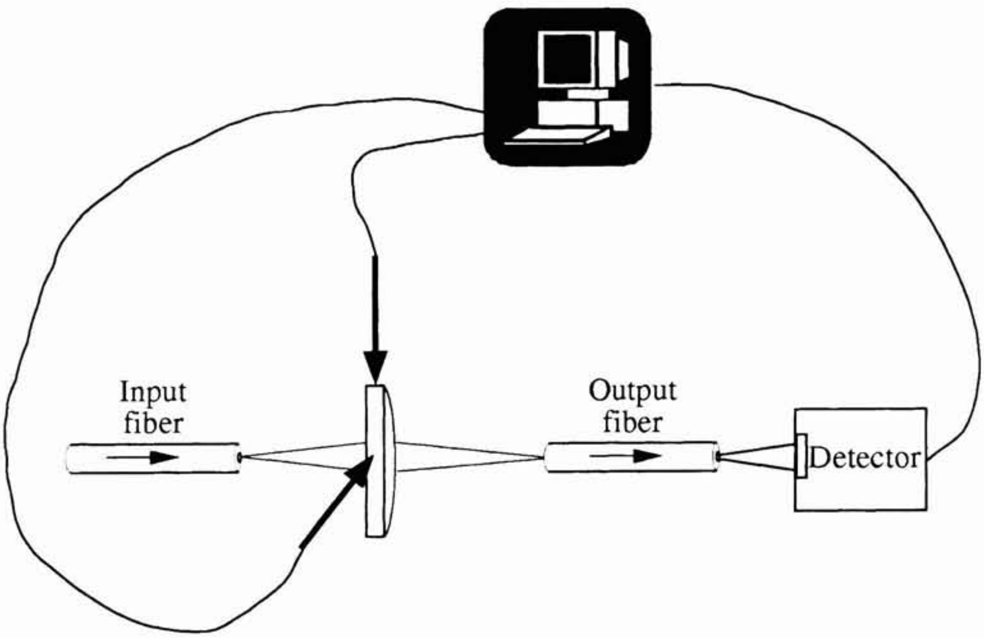

Figure 5. Experimental setup with feedback loop.

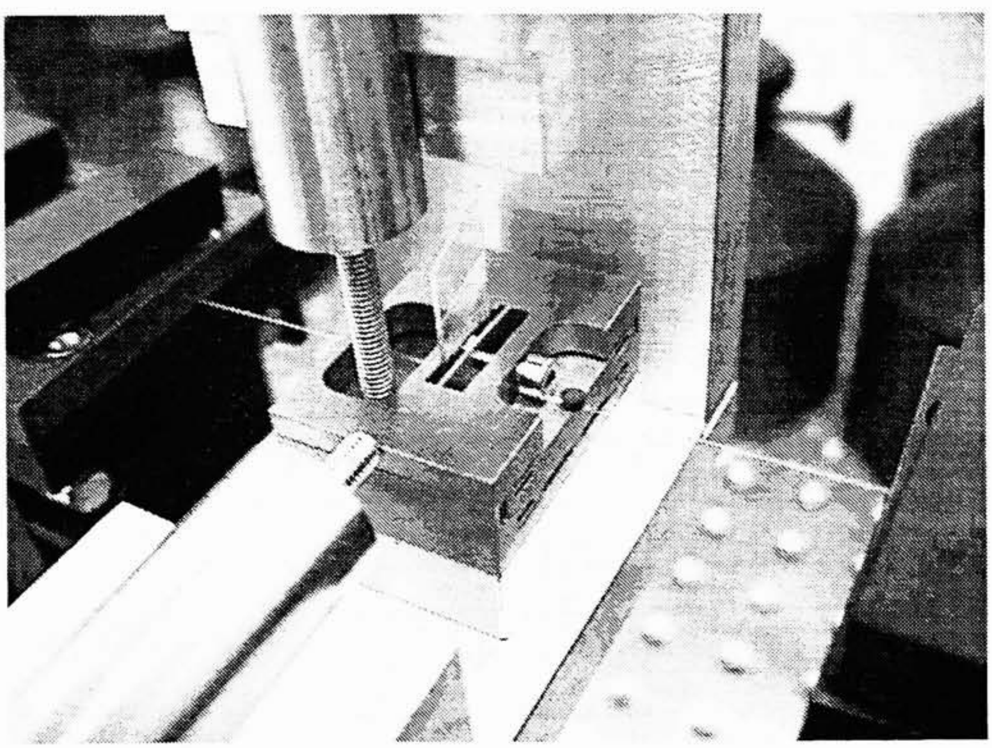

Figure 6. Detailed view of the experimental setup with the input fiber and the output fiber, the two actuators and the quartz substrate of the microlens.

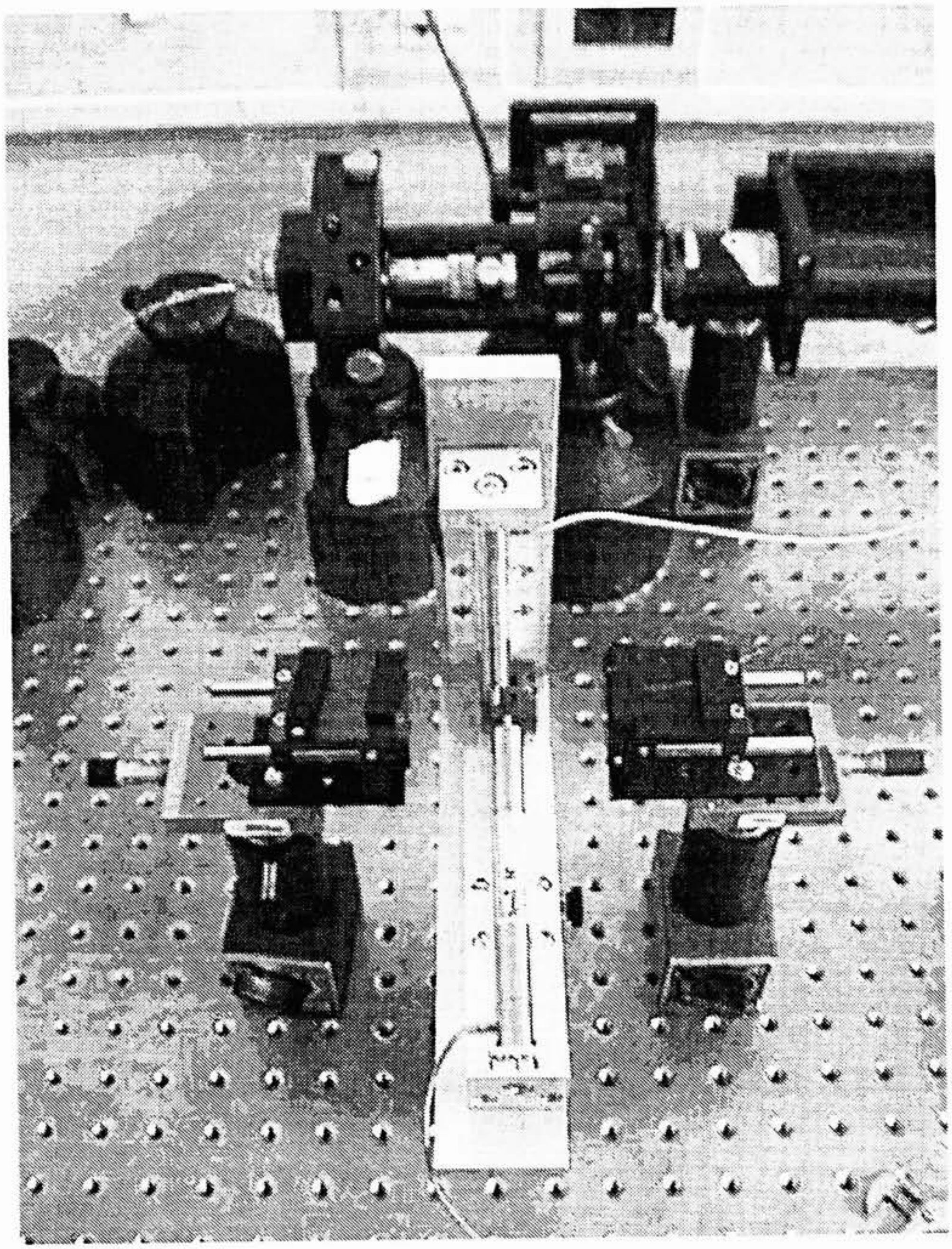

Figure 7. View of the XY-stage with the two piezo-electrical actuators and the two translation stages for the fibers.

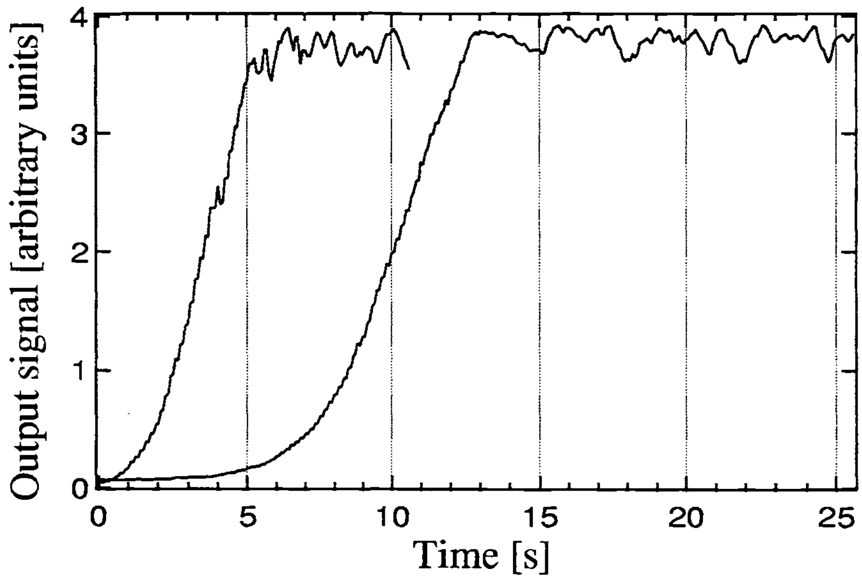

Figure 8. Output signal during the fine positioning of the lens using the feedback loop. Two initial situations are represented.

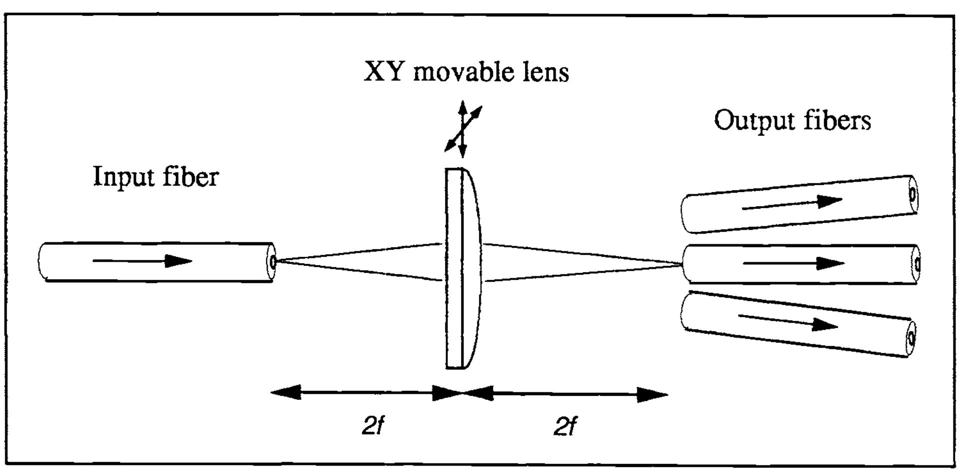

Figure 9. Setup of a 1x3 switch.