Subsurface damaged layer reduction with atomic force microscope scratch nano machining on optical fiber end plane

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Abstract

Atomic force microscopy (AFM) was used to conduct nano-micro scratch machining. This machining process is thought to reveal the fundamental characteristics of the polishing, which uses a very small cutting edge. We report on the reduction of the subsurface damaged layer by using AFM machining in this paper. The machining damage made by the harder AFM scratching is machined by AFM scratching using a lighter load. The damage layer reduction is estimated by optically measuring the return loss of the fiber end plane.

1. Introduction

We have been studying the atomic force microscopy (AFM) nano scratch machining for fundamental polishing characterization [1], [2]. The advantages of using AFM scratching in our study are available to use a well-defined cutting edge, trajectory, and process load. This nano-micro machining is thought to reveal the elementary-step of the polishing, whose mechanism is not yet well-understood. We use the optical fiber for telecommunications as the specimen. It is made of highly pure silica glass. The chemical aspects of the polishing can also be investigated for various cutting edge materials and by changing the scratching atmosphere. Furthermore, the subsurface damage can be optically estimated. An optical-fiber retro-reflection measurement can be used to characterize the subsurface machining damage layer by machining the core part of the optical fiber end-plane. We report in this paper that the process damage made to the optical fiber plane by using heavier load AFM scratching is reduced by using a lighter load AFM scratch machining. Reduction of the damaged layer is verified by checking the change in optical return loss. The lighter and shallower scratch machining will help to simulate the finish polishing using fine abrasives.

2. Experiments

The scratching of an optical-fiber end plane is illustrated in Fig. 1. A region of about 20 μm × 20 μm that includes the optical core, which is located at the center of the optical fiber, was scratched. The core, through which the light signal propagates in a single-mode optical fiber, was about 10 μm in diameter. The experimental setup for the scratching is shown in Fig. 2. The AFM was improved to fit our experimental setup. The optical connector ferrule, which embeds the optical fiber, is inserted into a hole in the AFM stage, which includes a tray for liquid. The O-ring sustaining the ferrule prevents liquid from leaking out. This apparatus enables for the AFM scratch machining of the optical fiber end plane located on the connector ferrule end in liquid. AFM scratch machining can simulate the general polishing by scratching within a liquid. The optical connector ferrule has a fiber pig-tail. So, any subsurface damage can be optically estimated. The subsurface damaged layer can be characterized by taking a retro-reflection measurement. Previous studies [3] showed that diamond abrasives of various diameters uniformly increase the silica glass optical index of subsurface damaged layer from 1.45 to 1.53. In contrast, increasing the abrasive diameter increases the layer thicknesses. These cause various return

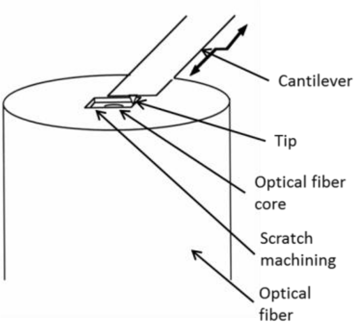

Figure 1: AFM scratch machining to optical fiber end.

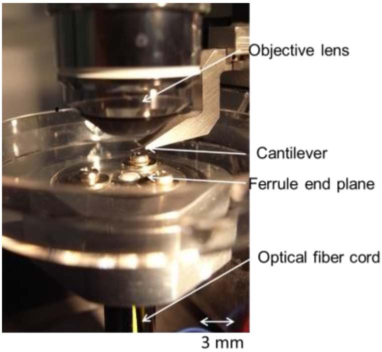

Figure 2: Photograph of improved AFM system.

losses with various abrasive diameters. In the experiments we use 0.1-μm curvature radius diamond tips. The scratching speed was one second per line, and the scratch scanning interval was 0.04 μm. Therefore, 512 scratches constituted the scratched area.

3. Results

An optical-fiber end plane scratched in pure water using a diamond tip is shown in Fig. 3. The machining load was 50 μN. The scratched bottom plane appears to be very smooth. The change in machining depth with this load increase is shown in Fig. 4. The depth increases almost proportional to the load. The return loss is shown in Fig. 5. It is 57 – 58 dB on average before the scratching. The end plane initially had very little subsurface damage due to the fine polishing using a silica abrasive. However, the return losses decrease to 40 – 42 dB after the scratching. This means that the damaged layer was caused by the scratching. These figures show that the heavier loads created the deeper machining and the thicker the subsurface damaged layer. Fig. 6 shows the change in machining depth based on the machining steps, and Fig. 7 shows the optical return losses after each step. The first step in both figures was machined at 80 μN. The second and third steps used lighter loads of 20 and 30 μN for scratching the same area. Fig. 6 shows that the lighter load machining following the larger weight machining causes a deeper scratch. On the other hand, the return losses are higher (Fig. 7). The higher return loss indicates that there was a thinner damaged layer [1]. These results mean that the lighter load scatching, which creates a thinner damaged layer, removes the thick damaged layer, which is made using a larger load.

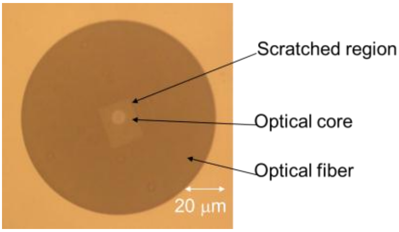

Figure 3: Nano-scratch machining to optical fiber end plane

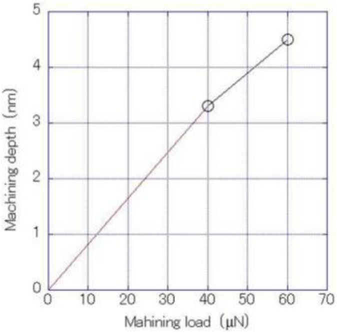

Figure 4: Change in machining depth based on machining load.

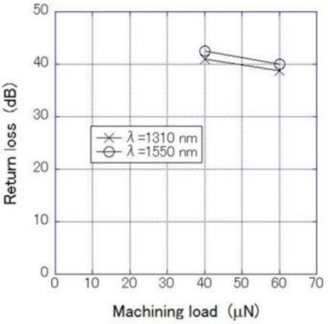

Figure 5: Decrease in return loss with increase in machining load.

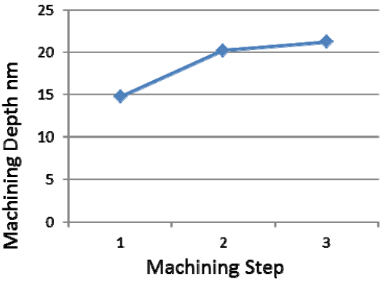

Figure 6: Change in machining depth based on machining steps.

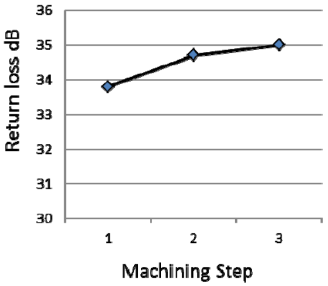

Figure 7: machining steps Change in return loss based on.

4. Conclusion

AFM nano-scratch machining of optical fiber ends was conducted. The damaged layers are characterinzed by measuring the optical return losses. It was found that a lighter load scratching reduces the subsurface damage, which was made by using heavier load scratching.

References:

[1] S. Matsui, F. Ohira, S. Umemura, K. Matsunaga, and K. Koyabu, Precision Science and Technology for Perfect surface, (1999) pp. 893

[2] S. Matsui and J. Kobayashi: Characterization of damaged layer of optical fiber end by AFM scratch machining, Journal of Abrasive Technology (in Japanese),54 No.10 (2010) pp. 607

[3] S. Matsui, F. Ohira, K. Matsunaga, and Y. Kikuya: Proc. of 7th International Precision Engineering Seminar, (1993) pp. 699