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学位論文題目　A Study on a Multi-link Active Catheter with Integrated CMOS Interface Circuits
(通信・制御用 CMOS 集積回路を内臓した多関節型能動カテーテルに関する研究)
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論文内容要旨

Recently, microsystem technology has become a focus of interest to many engineering areas and particularly to the medical field. One of the most promising applications based on microsystem technology in the medical field is minimal invasive therapy, which is increasingly being used as treatment method. For instance, catheter-based interventional diagnosis and therapy have become popular in current surgical procedures. Although many commercial catheters are available today, they offer limited directional movement and exhibit a substantial patience risk. The catheters also require specialized surgeons and additional equipment for monitoring; for example, X-ray equipment and therapeutic agents. The limited activity and controllability results in great pains and some damage to patients as well as fatigue to surgeons. Therefore, new types of catheters capable of active movement with intelligent functions are in demand. We have proposed a smart active catheter, which is capable of navigating along blood vessels under remote control from outside. In addition, this system can also be used in variety of other applications such as inspection and maintenance of machines in narrow and complex spaces.

In the past few years, studies have been reported on the development of the smart catheter. SMA is an attractive actuator for catheter because of its high power-to-weight ratio, simple design, light weight, large displacement and requires only a current source to drive the material compared to other microactuators such as piezoelectric, electrostatic and bimetallic microactuators. A prototype active catheter previously presented by our group was fabricated using micromachined silicon-glass links. But this catheter link fabrication and assembly were extremely complex because the link was a 3-dimensional structure with metal patterns for electrical interconnections to the three SMA actuators. Therefore, we found that Molding Interconnect Device (MID) technology is useful to fabricate the links of the active catheter because small polymer structures which have conductive metal patterns can be made by mass production using a molding technique. The MID technology has already been practically used for IC sockets, connectors, and sensor packages. A prototype of the active catheter using MID polymer links was proposed. By using polymer links, the active catheter was fabricated simply with very high yield. However, a major problem in these two types of the active catheter presented above is that too many lead wires are required for controlling the SMA actuators. The total number of lead wires required is at least equal to the number of the SMA actuators used. To minimize the number of lead wires in such microsystems, integrated circuits with multiplexing function should be embedded.

This dissertation describes the result of an attempt to achieve a smart active catheter using the micromachining technology. The contribution of this work is the development of multi-link active catheter with integrated CMOS interface circuits for communication and control (C&C IC) less than 2.0 mm of a diameter. The distributed micro SMA actuators were used for multiple degrees of freedom movement. This active catheter has only three common lead wires to interface with an outside controller. Any link can be addressed and each SMA actuator is controlled by the C&C IC mounted on the link. The three lead wires are built-in the C&C IC using CMOS-compatible polyimide-based process in order to reduce the size and simplify the assembly work. By using SF_6-based Si RIE (Reactive Ion Etching) and xenon difluoride (XeF_2) vapor-phase Si pulse etching, the C&C IC chips with flexible interconnect leads are released from the wafer.

In the Chapter 2, the technologies used to fabricating the microsystems are mentioned in next Chapter. In the Chapter 3, the current catheter system is reviewed and then the multiple links active catheter with the C&C IC chips, including the microactuators, is described. Then bending principle, model and design of the active catheter is presented in Chapter 4. Next, the interface system for communication and control is described in Chapter 5. This is followed by descriptions of the fabrication process and the assembly process of the smart active catheter, including the results of process in Chapter 6. Then, the experiment and test results are described in Chapter 7. Finally, the results of this work and its future prospect are discussed.

審査結果の要旨

カテーテルは血管内で検査や治療を行う低侵襲医療に用いられるが、特に脳内などにこれを導入するには曲がりを体外から自由に制御できる必要がある。このため多数のアクチュエータが分布し、蛇のように柔らかく動く機能を持つ能動カテーテルの開発が期待されている。

本論文は、多関節型能動カテーテルの各関節に通信・制御用 CMOS 集積回路を内蔵し、３本のリード線で動くものを試作して、その研究結果を纏めたもので、全編８章よりなる。

第１章は緒論である。

第２章では、この研究に関連するマイクロシステム技術、特にマイクロマシニングと呼ばれる微細加工技術について概観している。

第３章では、能動カテーテルのシステム設計に関して述べている。複数の関節から成る外径 2mm 程のカテーテルで、関節の間に形状記憶合金のコイルが配置されており、そのコイルに通電して加熱することで各部が曲がるものである。

第４章では、曲がりに関する設計とシュミレーションに関して述べ、形状記憶合金のコイルなどについて設計指針を明らかにしている。

第５章では、各関節に通信・制御用 CMOS 集積回路を取り付けたシステムについて、３本の共通リード線で信号を多重化する回路や、形状記憶合金のコイルに通電するトランジスタスイッチなどの設計を行っている。

第６章では、製作と組立について述べている。通常の集積回路と異なり、装着し易くするために集積回路チップにリード線が付いた状態で製作している。

第７章では、その動作試験結果について述べており、この多重通信機能を内蔵することで、実用的な能動カテーテルが実現できた意義は大きい。

第８章は結論である。

以上要するに本論文は、通信・制御用 CMOS 集積回路を内蔵した多関節型能動カテーテルに関する研究を行い、その設計指針を明らかにしたもので、機械電子工学の発展に寄与するところが少なくない。

よって、本論文は博士(工学)の学位論文として合格と認める。