Integration of a photovoltaic remote driver with high-voltage MEMS using standard CMOS technology

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1. Introduction

Since its invention around 1950s, transistors (later called as IC, and then LSI) and solid-state miniaturized sensors (later called as MEMS) have continuously evolved and have become essential components for everybody's life style. The trend continues in an accelerated way in the 21st century – more and more MEMS integrated LSI devices will appear to provide high functionality in a networked society. Such growth of application fields, however, leads MEMS designers to develop a lot of different devices in shorter turn-around-time. It is clear that MEMS need some quick and efficient research and development scheme. One guiding principle is that such integrated devices may take advantage of common technologies despite diverse applications. By developing common technologies beforehand, latency to obtain research outcome will drastically be shortened. The technology may include remote power transfer [2] and / or energy harvesting [3], active (non-silicon) sensing material [4] and / or actuation material [5] integration, and large (macro) -scale integration of silicon devices on flexible substrates [6]. The author's group is conducting such "integrated-integrated circuits" research together with specialists over the world, while managing over 150 yearly projects by over 100 independent research groups using supercleanroom of UTokyo VDEC. The unique advantage of UTokyo VDEC is that it has four functionalities (CAD, LSI, Test, and NanoFab) under one roof. Integrated MEMS-LSI research can thus easily be performed through UTokyo VDEC [1]. The scheme is to fabricate VLSI circuit and post-process in VDEC's Nanotechnology Platform Cleanroom. By such scheme reliability (due to foundry) and new functionality (due to custom process in platform) are simultaneously obtained. In the talk, an integrated remote power transfer device is presented.

2. High-voltage Photovoltaic Cells and Control Circuits Integration with MEMS device

MEMS devices are known to work with "high voltage (HV)". Absolute value may vary from around 10V to over 100V. The important thing is that the working voltage is derived from physics to satisfy its device performance request. Once defined, MEMS designer must cope with requested voltage. Inspired by pioneering works of on-chip high voltage sources, dated from 1980s, the authors are proposing a scalable HV source for MEMS integration. The basic idea is to fabricate a series-connected P-N junction in an LSI fabrication foundry. The P-N junction as-is fabricated does not give HV because all components are connected in parallel by substrate. The authors therefore propose, as shown in the Fig.1, to fabricate P-N junctions on a Silicon-on-Insulator (SOI) substrate, and physically separate

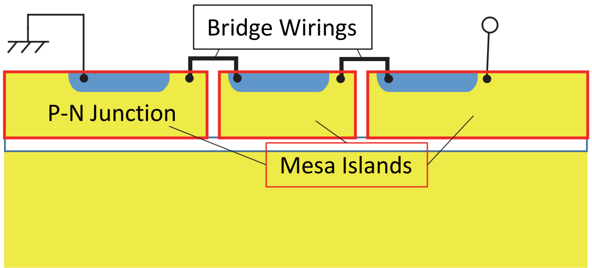

Fig.1 Schematic view of mesa-isolated HV photovoltaic cell

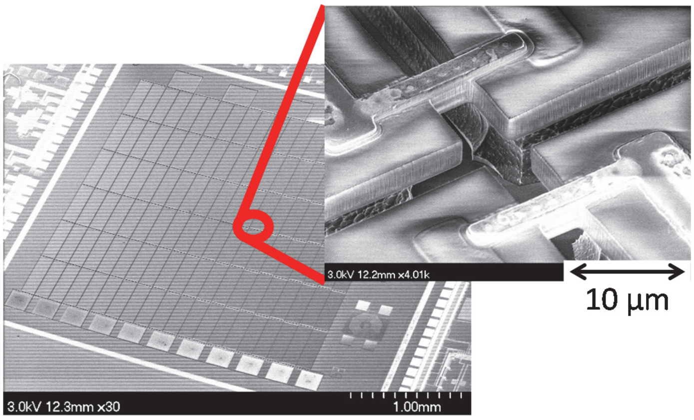

Fig.2 SEM view of fabricated HV-PV cells and close-up SEM view of bridge wirings.

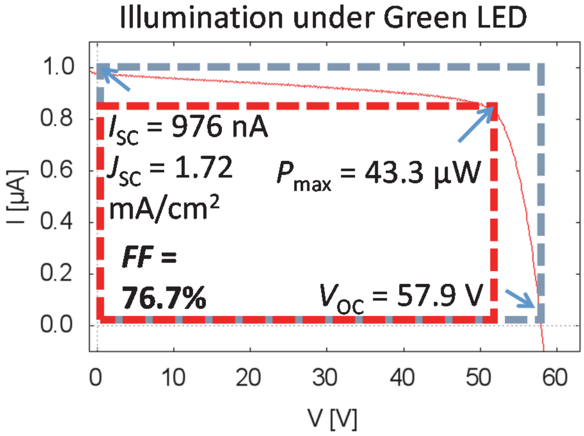

Fig.3 I-V characteristic of the HV-PV

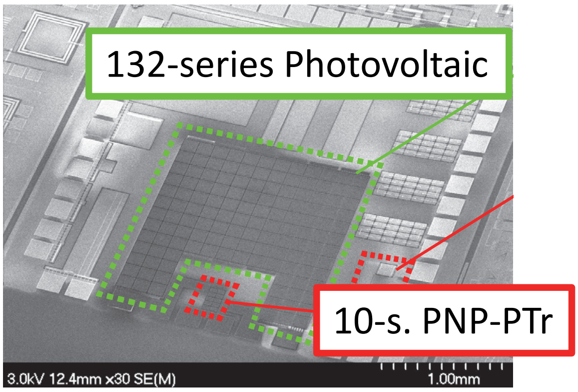

Fig.4 Discharging Controller Integration

unit cells by silicon deep reactive ion etching (DRIE). A combination of anisotropic and isotropic DRIE can remove substrate below LSI wirings that connects P-N junctions in series (Fig.2). A series-connected, physically (Mesa)-separated P-N junction photovoltaic is therefore obtained. At the first trial, a high-voltage generation function was successfully be obtained (Fig.3). The device was then combined with a couple of control devices such as HV-tolerant discharging for high-speed MEMS device operation. Remote operation (i.e. turn-on and turn-off) of MEMS device was demonstrated with wavelength multiplexing scheme – casting with green light made HV photovoltaic generate charging, and with red light made P-N-P transistor active, thus rapidly discharging the capacitive MEMS (Fig.4). The practical advantage of proposed method over previous work is its device quality: the device showed a fill-factor (i.e. ratio of maximum available power [W] to the product of maximum current and voltage [VA]) of 76.7%. The best fill factor of Silicon photovoltaic cells are known to be around 79%. Such close-to-ideal characteristics owe to P-N junction fabrication at foundry. On one hand, foundry provides very high quality silicon devices but does not accept to add any new processes before showing its economic interest. On the other hand, university MEMS platform accepts new trials but prone to be contaminated. Such new-functional – and – high-quality device was achieved by combination of advantages of foundry and university. Furthermore, the SOI substrate can also be used as mechanical device, hereby accelerating integrated MEMS research.

3. Integrated Device Research through Autonomous Distributed Micro Moving Objects

To extend such technologies, the author's group have made a couple of "top-down" application research projects as shown in Fig.5. The project aims at realizing an autonomous and / or self-movable tiny entities. The projects include an arrayed microactuator conveyance system with object recognition function, wireless powered water-sliding microrobot (pondskater)[5], and recently an autonomously movable and attach-detachable micro agents (programmable matter). By means of the CNRS international research unit (UMR 2820, LIMMS), microconveyor project was financed twice and currently programmable matter project is financed by french national research agency (ANR). Through such application-oriented research, necessary devices and associated integration technologies are developed and readily be used through nanotechnology platform. The author calls such research model a "University-centered linear model". Due to the open application, research result can be openly disclosed to everybody – a particular developer can take and optimize such results according to his application.

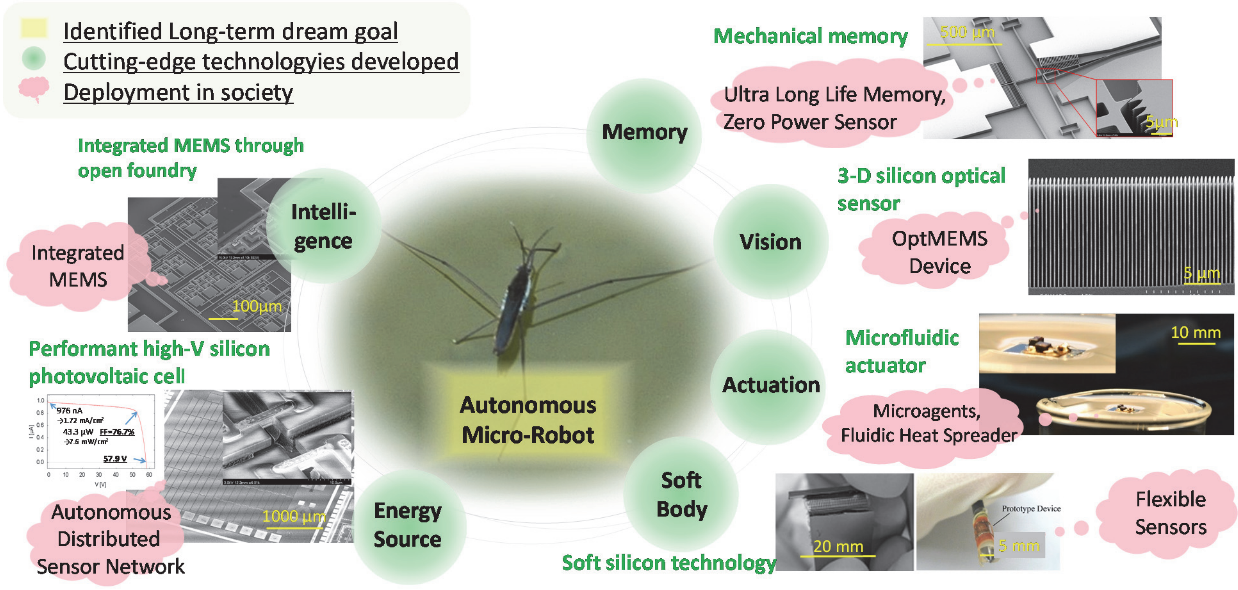

Fig.5 A University-centered linear model applied for integrated microsystem.

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