

TRENDS IN PHOTOVOLTAICS AND THEIR APPLICATION TO MEMS

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Abstract: Photovoltaics has advanced tremendously over the past several decades. In addition to the traditional single crystal silicon cells, new materials such as organic semiconductors as well as high performance inorganic materials are available. The application of these materials into MEMS suggests unusual designs or design tradeoffs; for example, unlike utility applications where cost per watt is the determining factor, in a high performance, area-constrained MEMS system, total efficiency may be the determining factor. Other factors such as physical flexibility and voltage output may also lead the PV designer into different solutions. Various technology solutions with efficiencies ranging from 3% (organic) to nearly 50% (multijunction) cells will be reviewed. Examples of the use of MEMS technologies in the manufacture of PV cells, such as metal-wrapped current collectors for shading minimization and formation of extremely thin silicon sheets from bulk materials, and their potential application to MEMS fabrication and integration will be presented.

Keywords: photovoltaics, solar cells, energy harvesting, fabrication

INTRODUCTION

Photovoltaics (PV) is the direct conversion of sunlight into electrical energy using a rugged and simple semiconductor device commonly known as a 'solar cell'. PV devices require very little maintenance and can provide stand-alone power ranging from microwatts to megawatts. Hence they can be used to power a variety of energy-consuming systems of multiple scales, ranging from integrated circuits and microelectromechanical systems (MEMS) to large-scale utility systems. PV has advanced tremendously over the past several decades and can now offer more options for power supplies. The cost of PV has decreased by a factor of approximately 80 since 1975 and is now within striking distance of grid parity. In many parts of the world it is already competitive with fossil fuels. Worldwide cumulative PV installation has increased from 1 GW in 2000 to 65 GW today, making it one of the fastest growing industries. In addition to traditional Si cells, new materials such as organic semiconductors as well as high performance inorganic materials are being used for PV with significant progress in efficiency [1].

PHOTOVOLTAICS FOR MEMS

The tremendous successes of PV on the industrial and utility scales can also potentially be leveraged for the powering of MEMS devices. However, the MEMS applications of PV may require unusual designs and design tradeoffs from the conventional PV point of view. For example, in typical utility applications, available area is relatively unconstrained, and cost per watt (as opposed to, e.g., efficiency alone) is a major driver for designs.

However, in an energy harvesting MEMS application, area is severely constrained; in these applications, a higher efficiency, higher cost multijunction or non-silicon cell may be appropriate. In addition to area-constrained efficiency, other design constraints present in MEMS applications may include flexibility, voltage output, illumination level, and form factor, potentially leading to significantly different solutions than might be expected from traditional PV.

To perform its intended function, a MEMS device or system needs a power source; in applications where the device is isolated (such as remote sensing), the power supply must be self-contained or based on environmental energy scavenging. Self-contained options include traditional primary batteries and micro-fuel cells, while scavenging options include magnetic-field-induced power and voltage supplies, mechanical energy scavenging, and PV, potentially coupled to rechargeable lithium micro-batteries and miniature fuel cells.

Among these scavenging options, PV offers an excellent size-to-power density ratio compared to other sources and can be fabricated and integrated as an on-board low cost and compact autonomous power supply for MEMS. However, the voltage and current requirements of MEMS devices and systems can be quite different from the voltages and currents traditionally available from PV. For example electrostatic MEMS usually require a power source with driving voltages ranging from tens to hundreds of volts. In contrast, a typical 260 W 1.65 m² solar panel used for rooftop applications consists of 60 large area (239 cm²) silicon cells, each producing ~9 Amps of current and ~0.5 volts. Therefore, a large

number of tiny cells need to be fabricated and interconnected in series on very small area ($\sim 1 \text{ cm}^2$) to meet the power, voltage, space and form factor requirements of MEMS devices. In addition, these cells may need to be isolated from the substrate to provide isolation between microsensors, circuitry and the solar cell solar power supply.

Even though 15-24% efficient Si solar cells are the workhorse of the PV industry today ($\sim 90\%$ market share), various technology options ranging from low-cost low efficiency ($\sim 5\%$) organic cells to high cost high-efficiency ($>40\%$) multijunction cells are now available. Other promising contenders include amorphous Si (a-Si), CdTe and CIGS (copper indium gallium selenide) thin film solar cells with efficiency in the range of 8~12%. Thin film and organic solar cells are often easier to fabricate and integrate with MEMS because of their ability to be deposited on foreign substrates, flexibility, thin absorber layers, and ease of isolation and interconnects. Some newer device concepts like interdigitated back contact (IBC) and metal wrap through (MWT) cells, which allow both contacts on the same side of the wafer, may facilitate the integration of high performance wafer based Si and GaAs devices with MEMS. In addition, novel exfoliation technologies being developed for PV can now produce thin (10~50 μm) and flexible Si and GaAs cells. One such technology is called SOM (semiconductor on metal) which begins with forming a metal film over a bulk crystalline material followed by thermal and mechanical processes which generate internal stress and exfoliate 10-50 μm material which is flexible and rugged because of thin metal back. Another technology uses hydrogen ion implantation to create a weak plane at the desired depth followed by rapid thermal anneal to peel off 10-50 μm thick silicon 'wafers' from an ingot, eliminating the need for sawing and preventing the kerf loss. Various cell concepts and technology innovations in PV will be reviewed.

PV-MEMS INTEGRATION

Some examples of PV-MEMS integration will be presented, including a miniaturized high voltage solar cell array based on multijunction a-Si cells (total area 1 cm^2) to drive electrostatic MEMS [2]. In this example, 100 series-connected triple junction a-Si cells produce 150V V_{oc} and 2.8 μA J_{sc} under AM 1.5 illumination to drive a movable micro machined mirror, the deflection of which is controllable by incident light intensity. The cell technology involved deposition of a-Si, transparent conducting oxide (TCO), and metal films on a Si substrate, followed by

mesa isolation of individual cells and series cell interconnection by photolithography. Similarly, a series-connected 20 tiny organic cell module (total area 2.2 cm^2) has been used to drive a MEMS-based microsensor [3]. This cell technology involved spin-on deposition and patterning of the anode, spin-on coating of donor and acceptor organic layers, and evaporation of an Al cathode through shadow mask.

CONCLUSIONS

PV is an attractive candidate for powering MEMS devices and systems. Leveraging the tremendous advances of photovoltaic technology over the past several decades, a large number of options are now available to the MEMS designer. This paper and presentation has attempted to point out the pros and cons of various PV technologies for MEMS applications.

REFERENCES

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