The State of MEMS in Israel

A Site Visit Report

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Microelectromechanical Systems (MEMS)

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I. INTRODUCTION

MicroElectroMechanical Systems, widely referred to as "MEMS" in the U.S. and as "Microsystems" in Europe, is an explosively growing field in which microfabricated devices are being developed for a broad range of measurement, actuation, display, and related functions. MEMS uses the technologies developed for microelectronics, extended by additional processes such as wafer bonding, micromachining, and electroforming, and is an important key in interfacing electronics to the non-electronic world. Like the microelectronics industry of thirty years ago, MEMS is now in a highly innovative state of development, with new ideas emerging at a rapid pace. Thus, while most efforts to date have involved mechanical devices (e.g., pressure sensors, accelerometers, and gyros) and have given rise to the new field of micromechanics, other recent MEMS work has given birth to microfluidic components (including microchemical systems and microanalysis "laboratories on a chip") and to integrated optical systems. Both of these areas are rapidly becoming the focus for major worldwide efforts in their own right, opening up whole new fields of study and promising important commercial products.

Much of the excitement associated with MEMS is due to the fact that with a relatively modest set of micro fabrication technologies, a very broad array of devices can be realized, with a revolutionary effect on many different application areas. In process control, precision sensing and actuation devices will allow adaptive control of production equipment at levels never before possible, including tool control to support advanced microelectronics manufacturing. In defense, MEMS is providing vital new capabilities in battlefield awareness, vehicular control, and reconnaissance. In health care, a new generation of implantable diagnostic and therapeutic devices are being developed along with wireless wearable health monitors and external diagnostic systems. Chemical microreaction chambers, DNA analysis systems on a chip, and sophisticated low-cost devices for environmental monitoring are examples. "Bio-MEMS" represents a joining of microelectronics with the life sciences, bridging the most important field of the last fifty years together with what is widely expected to be the most important field for the next fifty. Automotive/transportation systems depend critically on MEMS devices for engine control, adaptive suspension, and inertial position sensing. Combining sensors with wireless transceivers creates new opportunities for automation and monitoring systems. Exciting work to extend the maneuvering capabilities of high-speed aircraft with MEMS microactuators is also underway. Finally, integrated optical systems (scanners, switches for fiber-optic communications), single-chip transceivers using MEMS-based filters for low-power wireless communications, inkjet print heads, readout heads for high-density mass data storage, and microcombustion devices for use in small-scale electrical power generation are a few of the other examples of important emerging systems.

With its already strong program in microelectronics, Israel is well-positioned for participation and growth in the field of MEMS. Indeed, no country with a high-tech focus can afford not to be in MEMS. Without a strong MEMS program, numerous opportunities for new industries will be lost.

One of the attractions of MEMS is that while it represents an extension of microelectronics technology, it generally does not require the latest lithography generation to be competitive. While microelectronics today involves projection line widths of 0.18 microns and enormous cost, MEMS rarely requires feature sizes below 1.0 microns and thus can be addressed at much lower cost. MEMS is also a particularly important topic for academic research since it is highly interdisciplinary and involves a variety of fundamental issues ranging from materials through microstructures to devices and systems. Since the field is still relatively young, Israel could come up to speed rapidly, especially in newer areas such as micro-chemical and micro-optical systems. Participation in MEMS will allow Israel to play an important role in the new fields and industries being opened by this technology.

The Israel Academy of Sciences and Humanities convened an international study group on MEMS (referred to hereafter as the "Panel") that met during the week of May 23-27, 1999. The group was asked three questions:

- What is the present state of MEMS in Israel?
- What is the recommendation of the Panel concerning the directions Israel should take to develop an excellent MEMS program?
- What resources will it take to execute the recommendations?

This report presents the answers to these questions based on a two-day workshop held in Zichron Ya'akov on May 24-25, a site visit to the Technion on May 26, and a visit with Prof. Jacob Ziv at the Israel Academy of Sciences on May 27. The time for report preparation was intentionally kept short, so this report will be presented in a compact style, with relatively brief discussion.

The remainder of the report is divided into four sections:

- Activities of the Panel
- The present state of MEMS in Israel
- Recommendations
- Resources

II. ACTIVITIES OF THE PANEL

The activities of the Panel were the following:

A two-day Workshop on MEMS at Zichron Ya'akov, May 24-25
A half-day visit to the Technion, May 26
A meeting with Prof. Jacob Ziv, Israel Academy of Sciences, May 27

The original plan also included visits at RAFAEL, and at the new Microelectronics Center at Tel-Aviv University. Unfortunately, it was not possible to hold these visits. In the case of RAFAEL, the key technical individuals were in attendance at the two-day Workshop, and discussions with individual Panel Members did take place. However, there was no opportunity to see RAFAEL facilities first-hand, or to hold discussions with RAFAEL managers.

In the case of Tel-Aviv University, two of the key individuals gave technical presentations at the Workshop, but there was no opportunity for a full programmatic discussion of plans, facilities, and proposed research directions. When the fact that we were not to visit Tel-Aviv was revealed to Prof. Shacham-Diamand, he kindly made available a copy of the Executive Summary Proposal for the Establishment of the Tel-Aviv University Micro Fabrication Facility, dated December 1, 1998. This document, plus the technical talks presented at the two-day workshop by Tel-Aviv University personnel, are the only inputs the Panel has from that organization.

Prof. Shappir of Hebrew University attended the Workshop and did engage in discussions with a few individual Panel Members. There were no representatives from Beer-Sheva University or the Weizmann Institute. As a result, this report is silent on the activities and programs of the latter two institutions.

III THE PRESENT STATE OF MEMS IN ISRAEL

A. The MEMS Mission

The first issue confronted by the Panel was the proposed mission for a MEMS program in Israel. The Panel suggested four possible missions:

- Support existing local industry with relevant research and education
- Support a defense mission through focused research
- Stimulate the development of new industry
- Achieve international academic stature and visibility through excellence

In discussions with Prof. Paul Singer, head of the Israel Science Foundation, held at the Technion on May 26, it was clearly stated that for the purposes of this Panel, the MEMS mission was the achievement of international academic stature and visibility through excellence, with the conviction that the other proposed missions would follow in due

course. This was confirmed by Prof. Daniel Weihs, Provost of the Technion and original Chair of the Bikura Committee on MEMS that convened the Panel, and also by Prof. Jacob Ziv, head of the Israel Academy of Sciences. The Panel accepted this goal, and used it as a guidepost in its evaluation.

B. The Two-Day Workshop

At the two-day MEMS workshop held in Zichron Ya'akov, there were presentations from fourteen Israeli speakers (in addition to seven presentations from the Panel members). Of these fourteen, six were from the Technion, three were from RAFAEL, four were from Tel-Aviv University, and one was from the Hebrew University. Altogether, there were twelve projects discussed, covering such topics as inertial sensors, microoptical devices and components, microstructures for cooling semiconductor chips, actuators for fluid handling and control, CAD systems, implantable sensors, and process technology.

The Panel felt that some kind of "grading" or scoring of the individual projects presented at the workshop would be helpful in establishing a metric for the "present state of MEMS in Israel." Therefore, each Panel member gave a grade to each of the twelve projects for which the Panel member felt well-enough informed to express an opinion, and the majority grades were tallied. The grading criteria were:

A: Good research, of a quality appropriate to having a paper accepted by a top-quality international journal, such as the IEEE/ASME Journal of Microelectromechanical Systems;

B: Research that is not yet at A level, either because it is too preliminary, or needs some strengthening, but with suitable effort can become A level;

C: Research that shows significant weaknesses

The result of the grading process was as follows:

2 Projects received an A grade

8 Projects received a B grade

2 Projects received a C grade

The Panel recognizes that presenting these grades may cause some discomfort and speculation among the presenters at the Workshop over which project received which grade, and this is genuinely regretted. However, the Panel feels strongly that there is no way to measure the "present state of MEMS in Israel" without some fairly blunt evaluative comments. We feel that the Panel's grading scheme should be used as a baseline against which to judge the results of future review activities. If the mission of MEMS in Israel is to achieve international visibility through excellence, then one would expect that as the program matures, a similar review in the future would find about 50% of the projects receiving an A grade, the remainder receiving B grades because the

projects are too new, and no C grades. It is proposed that this goal of measuring excellence be adopted, and used internally as a metric for following and monitoring the growth and maturation of the MEMS program.

One way to promote strong research programs is to invite external (i.e., international) review of research proposals in the field of MEMS. Given that the program in Israel is new, it is difficult to obtain highly experienced reviewing of proposals from disinterested parties.

C. University Microfabrication Facilities

The Panel toured the microfabrication facilities of the Technion at the Kidron Microelectronics Research Center, and the VLSI Research Center in the Department of Electrical Engineering. The micro fabrication facilities are impressive, and with the addition of a few more pieces of MEMS-oriented equipment, will be a highly effective facility for MEMS research. In addition, the Panel learned that at least one start-up company is now using the Kidron Center facilities for development of their prototype. While the specific product is not in the field of MEMS, the fact that this kind of interaction can take place is viewed highly favorably by the Panel.

The Panel was unable to visit the facilities of Tel-Aviv University, and, therefore, cannot comment based on first-hand observation. The Panel examined the proposed Micro Fabrication Facility (TauMF), as described in the Executive Summary provided by Prof. Shacham-Diamand. The Panel views the Tel-Aviv proposal as extremely ambitious, covering too many topics and research thrusts. The Panel supports the establishment of a suitable fabrication facility at Tel-Aviv for microelectronics and MEMS to support both education and research. However, the Panel feels that the TauMF plan and the corresponding equipment purchases should be focused on a realistic and scaled-down set of objectives.

D. Industrial Infrastructure

The Panel was unable to visit the facilities of RAFAEL, and, therefore, cannot comment based on first-hand observation. However, there was discussion of facilities available to RAFAEL during the two-day workshop. What became clear was that while there are good facilities for highly specialized low-volume production, the infrastructure for volume manufacturing of MEMS devices is not readily available through RAFAEL.

There was a noticeable absence of industrial presentations at the two-day workshop. While it is dangerous to draw conclusions from negative data, it does suggest that the strongest present work in MEMS, excepting the RAFAEL work on gyroscopes, is not in industry. The Panel learned of a number of small companies that might have an interest in creating MEMS products, but the best assessment the Panel can make at this time is that the field is still in incubation mode at the industrial level.

This raises an important strategic concern. If the MEMS activities at the Israeli universities do manage to achieve a high level of international visibility through excellence, it will mean that, along the way, some highly practical devices will have been

developed, some possibly for niche markets, others possibly for mass markets. A major weakness at the present time is that there does not appear to be a suitable manufacturing infrastructure for MEMS in Israel. The semiconductor manufacturing arm of RAFAEL might provide some capabilities, and commercial companies such as Tower Semiconductor might in the future become interested in MEMS manufacturing, but currently the situation is weak. And while this weakness does not directly impact the goal of the universities to create strong MEMS programs, in the long run, the ability to manufacture will dictate whether or not device concepts developed in Israel can ever be built in Israel for either commercial or defense use.

E. Human Resources

While there has been an outstanding effort on the part of a few faculty members at the participating universities to design, fabricate, demonstrate, and test interesting and potentially useful MEMS devices, it is clear that there is a shortage of highly-experienced MEMS personnel within Israel. Faculty members who want to work in MEMS need to have some highly-experienced MEMS people at close hand, not only for the obvious role of leading the growth of an Israeli MEMS program, but also for the more subtle role of providing a nucleation point for learning about MEMS, speeding the path from novice to expert.

There are a variety of ways to address this shortage, several of which are listed below:

- Hiring outstanding (world-class) senior MEMS faculty from abroad
- Hiring promising MEMS-trained junior faculty
- Sending graduate students to major MEMS centers in the US and Europe for their PhD training
- Sending new PhD's to major MEMS centers in the US and Europe for postdoctoral assignments
- Sending existing senior faculty to major MEMS centers in the US and Europe
- Inviting leading MEMS experts for visiting faculty appointments

IV. RECOMMENDATIONS

The recommendations of the Panel are divided into the following subareas: General; Research Areas; Facilities; Personnel Development; Incentives; and Regional Opportunities. Each of these subareas is detailed independently below.

A. General

MEMS *research should be continued and expanded in Israel.*

Israel is a small country that can benefit greatly from concentration in high-tech industries, such as MEMS. In addition, the highly educated populace, as well as the high level of education of many of the immigrants, makes high tech industry even

more appropriate.

Israel already has an emerging MEMS program, and should make the necessary investments to maintain and grow this program. This will ensure not only academic excellence within MEMS, but also future economic benefit (e.g., high-tech products, establishment of small businesses).

Cooperation between institutions needs improvement.

While competition on technical research goals and activities is expected and healthy, cooperation on facilities planning and use is essential.

B. Research Areas

Specific areas within MEMS' *should be targeted*

Israel may not find it possible, especially in the early stages of its MEMS program, to cover all of the existing areas of MEMS. Israel will benefit from targeting and extending the already-existing physical and optical MEMS programs at the Technion, given the many telecommunications and defense applications of these programs. In addition, the interface of MEMS and life sciences (so-called "Bio-MEMS") is an excellent candidate, given Israel's outstanding tradition in the life sciences. For example, Tel-Aviv University may be in an excellent position to exploit this opportunity given its physical proximity to the Weizmann Institute, as well as the fact that substantial progress in this area of MEMS can be made with modest fabrication capability.

Establish an international peer review process in MEMS.

Since MEMS is a new field within Israel, advice from abroad in evaluating the relevance and excellence of proposed work will be important for objective determination of which new fields to enter.

C. Facilities

Infrastructure investments are needed at the university research centers.

The Panel was impressed with the clean room facility at the Technion, and it feels that this facility will be adequate for fabrication in much of the field of physical and optical MEMS. However, certain specific additions would greatly enhance the capability of the fabrication facility. In particular, the Panel recommends the addition of: an ICP (inductively-coupled plasma) DRIE (deep-reactive-ion-etcher), an addition to the existing Suss double-sided aligner to allow wafer-to-wafer fusion bonding, an anodic bonding apparatus, and expansion of the packaging capability.

The Panel supports the establishment of a suitable fabrication facility at Tel-Aviv for microelectronics and MEMS to support both education and research. However, the Panel feels that the TauMF plan, as proposed, and the corresponding equipment purchases should be focused on a realistic and scaled-down set of objectives.

Core support for facilities is needed.

First-class MEMS facilities are expensive to operate and maintain. Some portion of these expenses should be borne at the national level to insure continuity of research infrastructure and programs.

The university facilities should be made available to small business.

There are already examples of small-business use of university microfabrication facilities. The Panel encourages continuing to make such facilities available.

D. Personnel Development

Additional faculty in the MEMS area should be hired.

It is necessary to establish a "critical mass" of faculty-level MEMS researchers within Israel. Since MEMS is an interdisciplinary field, many 'traditional' departments may resist the hiring of MEMS-oriented faculty members, especially if the departments perceive that a slot for traditional hiring will be lost. We recommend that a national-level, targeted hiring of MEMS junior faculty be established, and if it can be done in a way that does not remove other faculty slots, that is highly desirable.

It is important to recognize that because MEMS is so highly interdisciplinary, there are several different kinds of faculty members needed for a successful program: technologists, applied scientists, application-oriented engineers. Only with a suitable mix of faculty members will a program be able to reach this critical mass, and be fully successful.

Clearly, hiring one or two world-class senior faculty in MEMS would be an excellent idea. We recognize that this may be difficult. However, we recommend that universities consider targets of opportunity for senior faculty hiring in this field.

Promote opportunities for MEMS study abroad

The Panel feels that an extremely effective way for Israel to build a MEMS program is to send outstanding graduate students to take their PhD training in world-class programs in the US and Europe. The fact that PhD students spend several years in deep immersion in a new field guarantees that when they return to Israel, they will bring the state of the art with them.

An alternative approach is through postdoctoral experience, and this should be encouraged as well.

Finally, we recommend that existing faculty members be given the opportunity to spend time in leading international laboratories abroad as a way of promoting a shift of emphasis in their research toward MEMS.

Attract senior visiting faculty in MEMS.

While it may be difficult to attract experienced senior faculty in MEMS to move from abroad to Israel for permanent positions, it should be relatively easy to attract such faculty for visiting appointments.

Encourage Israeli participation in international conferences.

The Panel observed that some of the work presented in the workshop was not up-to-date. One possible cause for this is the relative isolation of Israeli MEMS scientists until very recently. Thus, the Panel recommends that opportunities be made for Israeli scientists to travel to international MEMS meetings, whether they are presenting a paper at that particular meeting or not, in order for more of the current state-of-the-art in MEMS to be assimilated by Israeli MEMS researchers.

Organize topical tutorials and or short courses in Israel on MEMS.

The Panel recommends that Minding be provided to invite international experts in MEMS to give short courses and/or tutorials on several of the most relevant (to Israel) topics in MEMS technology This would have the beneficial effect not only of education, but also strengthening communication between institutions as well as potentially stimulating the entry of new institutions and/or industry into the MEMS field.

E. Incentives

Establish a multisite national Center of Excellence in MEMS.

One problem observed by the Panel is the relative lack of coordination between various MEMS-capable sites in Israel. One way to address this is to establish a MEMS center of excellence, e.g., an ISF Center of Excellence in MEMS, in which it is required that multiple institutions participate in a single research program.

Establish productive links with industry.

The panel recommends the establishment of funding mechanisms that will encourage industrial participation in academic research. Specifically, the Panel recommends providing matching funds for industrially-sponsored projects, thereby ensuring that industry has "bought-in" to the particular MEMS project.

An information infrastructure is needed.

We recommend the establishment of an internet-based communication center for MEMS researchers in Israel, and the creation of a national MEMS colloquium that rotates between MEMS research organizations.

F. Regional Opportunities

Exploit Israel's participation in the Fifth Framework Program of the European Union.

Israel has joined the Fifth Framework Program of the European Union, a scientific program that funds competitive research proposals in a variety of areas, including MEMS. This framework program typically requires joint proposals from several institutions and countries. Israel should examine the possibilities of joining with other member countries to submit proposals in this area. This will have two benefits: not only will this serve as a vehicle for enhancing collaboration with other MEMS research programs both internal and external to Israel, but it will also allow for a new pool of resources for MEMS research within Israel.

Position Israel as the regional center of MEMS in the Middle East

Israel has an opportunity to take leadership of the MEMS field in the Middle East. Already, meetings between the Israel Academy of Sciences, and its counterparts in the Palestinian Authority, Jordan, and Egypt have taken place. Assuming that relationships between these entities continue to develop, due to its excellent infrastructure Israel is well-positioned to become the regional leader in MEMS.

V. RESOURCES

Given the short time available for this study and report, it was not possible to make detailed cost estimates for the various infrastructural improvements and programmatic requirements. However, the Panel estimates (very roughly) that the equipment improvements needed at the Technion will require about 1.5 Million USD, and that the recommended partial support of the operation and maintenance costs of that facility would be on the order of 250 Thousand USD per year. There is already a detailed equipment proposal from Tel-Aviv University, with detailed cost estimates. As indicated above, we have some concerns about the focus of these funds, but not the amount.

We have also recommended hiring of personnel, funding of industrial collaborations, and support for international study and travel. We feel that these costs can be easily estimated within Israeli norms.