Humboldt/Princeton Strategic Partnership

Teaching and Research Collaboration

Project Description

Project Title:

Princeton-Humboldt Workshops on Novel Opto-Electronic Materials

Princeton Lead Organization and Proposal Leader:
Dept. of Electrical Engineering, Prof. Antoine Kahn

Humboldt Lead Organization and Proposal co-leader:
IRIS Adlershof, Prof. Norbert Koch

Princeton Faculty (Principal Investigators):
Antoine Kahn, Barry Rand, James Sturm and Sigurd Wagner (Electrical Engineering); Steve Bernasek and Jeffrey Schwartz (Chemistry); Lynn Loo (Chemical and Biological Engineering)

Humboldt Faculty (Principal Investigators):
Oliver Benson, Claudia Draxl, Joachim Dzubiella, Fritz Henneberger, Norbert Koch, Jürgen P. Rabe (Physics), Hans Börner, Stefan Hecht (Chemistry)

We hereby request funds from the Humboldt-Princeton Strategic Partnership program to organize two workshops to develop a long-term research and teaching collaboration between the two institutions with focus placed on novel opto-electronic materials. These workshops will lead to an application for an International Research Training Group (IRTG) (submitted to the DFG and the NSF) in 2014, and to the development of joint courses for student and teaching exchange between PU and HU.

1. Scientific research field

Future progress of our information-based society demands the concentration of opto-electronic functions with increasingly higher capabilities in smaller and smaller volumes. At the same time, steadily increasing mobility of individuals and the need for reliable flow of high

volume data calls for light-weight devices with mechanical flexibility, e.g., in smart clothing. Yet another pressing challenge is the efficient generation of energy from renewable sources, such as photovoltaics, which need to become available in the short-term in substantial quantity. Established materials have been pushed close to their intrinsic limits and many of the devices and systems using these materials are not light weight or bendable (e.g., silicon-based electronics). Furthermore, the primary energy required for the fabrication of presently established technologies is significant and could be reduced by developing new appropriate materials and production methods. Organic and hybrid organic/inorganic material combinations offer the possibility to overcome some of the current limitations.

The fields of organic electronics and opto-electronics have seen considerable advances in the past decade, with remarkable progress in light emission or harvesting, flexible electronics and sensors. Some of these applications are already successfully penetrating the market. Hybrid materials for opto-electronic applications are at a comparably early research stage. Both material classes, organic and hybrid materials, offer the possibility for direct printing from solution, which could enable large-scale low-cost fabrication of electronic and opto-electronic components and devices in a roll-to-roll (R2R) fashion. Further progress in this area depends critically on intensive research efforts on organic and hybrid semiconductor materials, with strong focus on material chemistry, electronic structure, mechanical properties, and device integration. Both Princeton University and Humboldt-Universität have a lasting and proven record of excellence in research on organic and inorganic materials for opto-electronics, and both have recently extended their efforts towards hybrid systems. Therefore, a joint PU-HU research effort aimed at elucidating some of the fundamental chemical, electronic, and photonic interactions in novel opto-electronic materials and their combinations, and at developing new device types and architectures, including manufacturing issues, appears as highly desirable for both institutions. Students (undergraduate and graduate) would be directly involved in this venture, through teaching and research projects, and would greatly benefit from such an interdisciplinary collaboration, from intellectual exchanges between groups and from personal visits at two prime institutions.

The Humboldt-Universität and Princeton faculty members named on this proposal are world leaders in various areas of organic, inorganic, and hybrid semiconductor materials, chemistry, physics, and devices. They have highly complementary strengths, techniques and facilities. Most important, a few of these faculty members already have a long-standing track-record of bi-lateral ties and collaboration. The Humboldt-Princeton partnership provides a wonderful opportunity to bring these collaborations to a higher level, where funding for international collaboration in the two countries can be leveraged.

The proposed "Princeton-Humboldt Workshops on Novel Opto-Electronic Materials" would enable the necessary initial exchange of PU and HU faculty and young researchers, who are active in the aforementioned research fields. The basic goal of the workshops is to identify and develop an overarching research project suitable for sustainable third party funding. As outcome of the two workshops, we target the development of a proposal for an International Research and Training Group (IRTG), funded jointly by the National Science Foundation (NSF) and the Deutsche Forschungsgemeinschaft (DFG) (see http://www.dfg.de/en/research_funding/programmes/coordinated_programmes/research_training_groups/in_brief/index.html for program details). The coordinated research projects will generate an active program of exchanges of undergraduate and graduate students and postdoctoral fellows between Princeton and Berlin, as well as concerted teaching activities at both universities in physics, chemistry, and electrical engineering.

2. Benefits for PU and HU international strategy and research program

During the past decade, both institutions have shaped their research portfolio in physics, chemistry, and engineering such that the topic novel opto-electronic materials and devices has become a cornerstone of institutional strategy.

At Princeton University, hybrid opto-electronic materials and devices have been one of the focal research areas in the laboratory of every faculty involved in this proposal. Kahn, Loo, Schwartz and Sturm are currently part of the NSF-funded Princeton Materials Research for Science and Engineering Center (MRSEC), in an interdisciplinary group working on the

integration of organic and inorganic semiconductors for photovoltaic applications. Schwartz and Bernasek have long collaborated in areas related to organic/inorganic hybrid interfaces. Finally, Kahn, Loo, Rand, Schwartz, Sturm and Wagner are currently working together to secure funding for research on new hybrid systems involving binary chalcogenide and organic semiconductors. Princeton very recently recruited a young faculty member (Rand), expert in that area, who will join our ranks in the summer of 2013.

At Humboldt-Universität, the topic of "hybrid materials for opto-electronics" (based on organic and inorganic semiconductors) has emerged as one of the key research fields on the Adlershof Campus. This is demonstrated by the concerted recruitment of five of the Principal Investigators (PIs) involved in this proposal during the past seven years (Börner, Draxl, Dzubiella, Hecht, Koch), and one new W3 professorship "Hybrid Devices", with an expected appointment late this year. Further evidence for the HU commitment to that research topic in Adlershof is provided by the SFB951 ("Hybrid inorganic/organic systems"; spokesperson: Prof. Fritz Henneberger) and the research agenda of the Integrative Research Institute for the Sciences - IRIS Adlershof (see http://www.iris-adlershof.de). Finally, in April 2013 the Wissenschaftsrat has recommended funding of a new laboratory building next to IRIS Adlershof, the dedicated research portfolio of this building will encompass organic and hybrid electronic and opto-electronic materials. Thus the present proposal lies at the heart of the Humboldt-Universität strategy in the natural sciences.

In spite of the solid involvement of HU and PU in the (broad) field of hybrid systems, we see considerable complementarity and distributed strength between the two institutions, on theoretical and experimental sides, on the chemistry of materials and on device fabrication and analysis. Forging a strong research bond would considerably leverage the existing individual strengths, and tremendously benefit students on both sides of the Atlantic. The two proposed workshops, the enabled joint research, the student exchanges, and the teaching activities would help realize the key targets of the Humboldt/Princeton Strategic Partnership as a true and lasting "Teaching and Research Collaboration". We will initiate bi-lateral third party funded research projects *with joint student supervision* in the United States and Germany, as well as increased student mobility between the two countries. The strong ties established between

Princeton University and Humboldt-Universität will facilitate further international integration through additional institutional and PI-based collaborations with top researchers in the Americas, Asia, the Middle-East, and Europe.

3. Involvement of HU/PU researchers and students

The HU and PU faculty members named on this proposal are world leaders in various areas of organic, inorganic, and hybrid semiconductor materials, chemistry, physics, and devices. They have highly complementary strengths, techniques and facilities. Most important, a few of these faculty members already have a long-standing track-record of bi-lateral ties and collaboration. The Humboldt-Princeton partnership provides a wonderful opportunity to bring these collaborations to a higher level, where funding for international collaboration in the two countries can be leveraged.

To accomplish the initiative's goals, we chose a truly multidisciplinary approach with highly specialized and skilled scientists from different disciplines, each one bringing a particular expertise, including theoretical modeling, organic, supramolecular, and inorganic synthesis, implementation of new methods for nanoscale studies, surface studies, photophysics, as well as device fabrication and characterization. We integrate different disciplines of the two academic institutions, all of the PIs actively participating in the training of the students and young researchers. Therefore, students and young researchers will naturally be exposed to different schools of thoughts in terms of disciplines, approaches, culture, techniques and will have the chance to operate in various academic environments, thereby also offering them a comprehensive set of complementary skills.

Aside from participation in all proposed activities, undergraduate and graduate students and postdoctoral fellows will be directly involved in organizing the two Princeton-Humboldt workshops, which will allow them to obtain hands-on experience in organizing larger scale scientific events. Satellite meetings will also be organized by young researchers independently, with the respective PIs only providing logistic support and acting as mentors. Ultimately, ideas

developed in the young researchers satellite meetings will serve as valuable input for developing the research agenda for the IRTG proposal.

4. Activities of the planned initiative

We request funds from the Humboldt-Princeton Strategic Partnership program to organize two workshops (duration of up to five days), one in the fall of 2013 in Berlin, and one early in 2014 in Princeton. The funds will cover travel expenses for 6-7 faculty members plus 5-6 graduate students and postdoctoral fellows from each side to travel to the partner institution.

The first workshop in Berlin will be a forum for detailed exchange on present research interests of all involved PIs. This forum will be used to identify the most promising potential common topics for an IRTG proposal. Additionally, the structure and contents of teaching curricula and the underlying philosophy of PU and HU will be introduced, to set the starting point for the development of joint courses, to be taught by PU faculty at HU and *vice versa*.

The second workshop in Princeton will serve to flash out the most promising research topic, based on intra- and inter-institutional discussions in the period between the workshops. The team of PIs and additional researchers will be confirmed, and their role in preparing the IRTG proposal will be defined. The set of joint courses for teaching exchanges will be developed.

In parallel to both workshops, there will be satellite meetings for young researchers, including undergraduate and graduate students, as well as postdocs. One aim of these meetings will be to enhance the young researchers' skills for presenting their own work in a setting that reflects that of international conferences. The second aim will be to familiarize them with the research topics of the PU/HU initiative, which will help them position their efforts within the wider context of novel opto-electronic materials.

5. Strategy for longer-term support of the initiative

The goal of the proposed workshops is to provide opportunities for face-to-face discussions, whereby faculty members and young researchers of both institutions will develop a research

proposal that will be submitted to the German DFG and the US NSF for funding under the Integrated Research and Training Group (IRTG) program (http://www.dfg.de/en/research_funding/programmes/coordinated_programmes/research_training_groups/in_brief/index.html). This program allows funding of student training (Bachelor, Master, Doctorate) in both universities of up to *nine years*. We anticipate submission of the IRTG proposal in 2014.

6. Profile of the peer institutions and their complementarities

The group of PIs assembled on the Princeton side is known for collective strength in surface chemistry, including the manipulation of organic and inorganic semiconductor surfaces for optimizing their electronic structure, and in the functionalization of these surfaces for enabling the integration of thin films in hybrid, or hetero- structures. Furthermore, members of the PU groups are pioneers in non-conventional methods of manipulation of thin organic films that enable the fabrication of novel hybrid devices. Device physics is also a key strength of the engineering group of PU PIs.

The strength of PIs in the Departments of Chemistry and Physics of Humboldt-Universität, most of them members of IRIS Adlershof, lie in synthesizing novel opto-electronic materials and unraveling their fundamental electronic/optical properties and elemental coupling mechanisms. On the other hand, the abilities (in terms of expertise and infrastructure) to fabricate and optimize opto-electronic devices, eventually up to demonstrator level, are presently limited. The same holds for controlling mechanical properties and devising innovative low-cost deposition techniques. This is mostly due to the fact that electrical and chemical engineering are not formally part of the Humboldt-Universität's structure. Consequently, teaming up with Princeton is the perfect way to include this complementary expertise in the Adlershof activities. Furthermore, the development of joint courses for the curricula of undergraduate and graduate students would enable us to include the full spectrum of expertise pertinent to novel opto-electronic materials in both institutions.

Appendix: referencing selection criteria

Statements regarding questions 7.-11. of the Humboldt/Princeton Strategic Partnership Teaching and Research Collaboration Grant Application Form.

7. How will the initiative contribute to the internationalization and long term programming of your department, center or program?

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facilitate further international integration through additional institutional and PI-based collaborations with top researchers in the Americas, Asia, the Middle-East, and Europe.

8. How will the initiative engage Princeton/HU scholars and students in the partnership?

The HU and PU faculty members named on this proposal are world leaders in various areas of organic, inorganic, and hybrid semiconductor materials, chemistry, physics, and devices. They have highly complementary strengths, techniques and facilities. Most important, a few of these faculty members already have a long-standing track-record of bi-lateral ties and collaboration. The Humboldt-Princeton partnership provides a wonderful opportunity to bring these collaborations to a higher level, where funding for international collaboration in the two countries can be leveraged.

To accomplish the initiative's goals, we chose a truly multidisciplinary approach with highly specialized and skilled scientists from different disciplines, each one bringing a particular expertise, including theoretical modeling, organic, supramolecular, and inorganic synthesis, implementation of new methods for nanoscale studies, surface studies, photophysics, as well as device fabrication and characterization. We integrate different disciplines of the two academic institutions, all of the PIs actively participating in the training of the students and young researchers. Therefore, students and young researchers will naturally be exposed to different schools of thoughts in terms of disciplines, approaches, culture, techniques and will have the chance to operate in various academic environments, thereby also offering them a comprehensive set of complementary skills.

Aside from participation in all proposed activities, undergraduate and graduate students and postdoctoral fellows will be directly involved in organizing the two Princeton-Humboldt workshops, which will allow them to obtain hands-on experience in organizing larger scale scientific events. Satellite meetings will also be organized by young researchers independently, with the respective PIs only providing logistic support and acting as mentors. Ultimately, ideas developed in the young researchers satellite meetings will serve as valuable input for developing the research agenda for the IRTG proposal.

9. What is the detailed plan for the operation and activities of the initiative?

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In parallel to both workshops, there will be satellite meetings for young researchers, including undergraduate and graduate students, as well as postdocs. One aim of these meetings will be to enhance the young researchers' skills for presenting their own work in a setting that reflects that of international conferences. The second aim will be to familiarize them with the research topics of the PU/HU initiative, which will help them position their efforts within the wider context of novel opto-electronic materials.

10. Explanation of the profile and interests of sponsoring departments or units and why and how they complement each other.

The group of PIs assembled on the Princeton side is known for collective strength in surface chemistry, including the manipulation of organic and inorganic semiconductor surfaces for optimizing their electronic structure, and in the functionalization of these surfaces for enabling the integration of thin films in hybrid, or hetero- structures. Furthermore, members of the PU groups are pioneers in non-conventional methods of manipulation of thin organic films that enable the fabrication of novel hybrid devices. Device physics is also a key strength of the engineering group of PU PIs.

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11. Describe the funding contributions from sponsoring units and a strategy for longer-term support for the initiative's sustainability.

The goal of the proposed workshops is to provide opportunities for face-to-face discussions, whereby faculty members and young researchers of both institutions will develop a research proposal that will be submitted to the German DFG and the US NSF for funding under the Integrated Research and Training Group (IRTG) program (http://www.dfg.de/en/research_funding/programmes/coordinated_programmes/research_training_groups/in_brief/index.html). This program allows funding of student training (Bachelor, Master, Doctorate) in both universities of up to nine years. We anticipate submission of the IRTG proposal in 2014.