Humboldt-Princeton Strategic Partnership
Grant Application 2015-16

Project Title:

Princeton-Humboldt Exchange Program on Novel Opto-Electronic Materials

Grant Category: Two-year open grant

Princeton Lead Applicant and Principal Contact:
Prof. Barry Rand, Department of Electrical Engineering

Humboldt Lead Applicant and Principal Contact:
Prof. Jürgen P. Rabe, IRIS Adlershof & Department of Physics

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, Christoph T. Koch, Norbert Koch, Jürgen P. Rabe (Physics); Stefan Hecht (Chemistry)

We request funds from the Humboldt-Princeton Strategic Partnership program to bring our collaboration between both institutions in the field of novel opto-electronic materials to the next level. In order to continue to strengthen and expand our collaboration and to make the program sustainable, we request funding to support our current interactions and to work to leverage longer term funding for this international collaboration for research and teaching. We wish to substantially strengthen the existing ties between the participating faculty PIs and their research groups through common research projects, through a planned international research workshop, and through an exchange program for researchers, including students, postdocs and faculty.

1. Scientific research field

Novel opto-electronically active materials will be urgently needed given the challenges our societies are facing with the development of various key technologies for the future. One of them is information processing, which demands the concentration of opto-electronic functions

with increasingly higher capabilities in smaller and smaller volumes. The 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. Another example is the efficient generation of energy from renewable resources by photovoltaics, which must become economically available in the short-term in substantial quantity.

Established materials have been pushed close to their intrinsic limits in many of these devices, and moreover systems using these materials are often 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 many 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 and light harvesting, flexible electronics and sensors. Some of these applications are already successfully penetrating the market. Hybrid organic-inorganic materials for opto-electronic applications are at a comparably earlier 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 a strong focus on material chemistry, electronic structure, mechanical and optical properties, and device integration.

2. Princeton-Humboldt Activities on Opto-Electronic Materials

Researchers at 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. 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.

At Humboldt-Universität the *Integrative Research Institute for Sciences – IRIS Adlershof*, chaired and co-chaired by two of the participating PIs (*Rabe* and *N. Koch*), was founded with a focus on Hybrid Systems for Optics and Electronics. Within the University's *Strategy for the Future*, funded through the German Excellence Initiative, IRIS has been provided with a new faculty position devoted to *Hybrid Devices* (this appointment is currently underway). Through this Excellence Initiative, IRIS is strengthening its international ties in this area of research, particularly with researchers at Princeton University and the National University of Singapore.

Research on Hybrid Inorganic/Organic Systems for Opto-Electronics is strongly funded by the German Science Foundation through a Collaborative Research Centre (SFB 951), chaired by participating PI *N. Koch,* and with all of the Humboldt-PIs participating directly. This funding supports ongoing research activities at the Humboldt-Universität in the area of hybrid inorganic/organic systems. It does not provide funding to directly support researcher exchange interactions.

Princeton participants in the NSF funded MRSEC (Materials Science and Engineering Research Center) have investigated the fundamental processes of self-assembly in organic materials and their applications in device configurations (*Loo, Kahn*). They have also investigated questions of the design and control of molecular materials interfaces (*Kahn, Loo, Schwartz*), and have interacted with investigators interested in inorganic semiconductor nanostructures and their interfacial properties. Individual investigator funding from NSF and other US funding agencies also supports studies of organic layer self-assembly (*Bernasek*), designed modification of inorganic/organic interfaces with self-assembled layers and by direct functionalization (*Schwartz, Bernasek, Kahn*), and studies of organic electronic device engineering (*Kahn, Rand, Sturm, Wagner*). This funding provides support for the ongoing research activities in these areas at Princeton University, but does not provide funding to directly support researcher exchange interactions.

Importantly, faculty members participating in the current proposal already have a long-standing track-record of bi-lateral ties and collaboration. The Humboldt-Princeton Strategic Partnership Program provides a great opportunity to bring these collaborations to a higher level, where funding for international collaboration in the two countries can be leveraged.

A joint PU-HU research effort has been established, aimed at studying the fundamental chemical, electronic, and photonic interactions in novel opto-electronic materials and their combinations, and at developing new device types and architectures, including addressing manufacturing issues. Students (undergraduate and graduate) are directly involved in this venture, through teaching and research projects, and greatly benefit from such an interdisciplinary collaboration, from intellectual exchanges between groups, and from personal visits at two prime institutions.

With the support of a seed grant from the Humboldt-Princeton Strategic Partnership-Program, two Workshops were organized and held, one at Humboldt-Universität in Berlin, October 27-30, 2013, and one at Princeton University, March 22-25, 2014. With the two day workshops of the PIs, followed by two day workshops for young researchers, the necessary initial exchange of PU and HU faculty and young researchers was established between the individuals who are active

in these research fields. These workshops were very successful in identifying small groups of Humboldt and Princeton faculty determined to pursue specific collaborative projects in both research and teaching, as well as laying the groundwork for joint publications. During the second workshop, an overarching research program was developed, focusing on interfacial self-assembly, semiconductor surface functionalization, opto-electronic device design, and questions of device manufacture and processing. Discussions were also carried out to plan for the preparation of proposals for longer term support of this collaboration. A plan was put in place to develop a proposal for an International Research and Training Group (IRTG), funded jointly by the National Science Foundation (NSF), through its Partnerships for International Research and Education Program (PIRE), and the Deutsche Forschungsgemeinschaft (DFG).

In order to explore suitable formats for teaching, participants in the current proposal from both institutions have started to interact on graduate teaching, with *Rabe* participating in a graduate course as Visiting Professor during the spring term 2014 at Princeton. In July 2014 *Draxl* and *Hecht* from Humboldt-Universität with *Kahn* from Princeton University co-chaired a KOSMOS Summer University at Humboldt-Universität on "Chemistry and Physics of Novel Materials for (Opto) Electronics". Participants as instructors in the Summer University included *Bernasek, Draxl, Hecht, N. Koch, and Rabe*, all collaborators in the Princeton-Humboldt Exchange Program of this proposal, along with several other Princeton, Humboldt, and National University of Singapore (NUS) experts in the field of materials for opto-electronics. In addition, several graduate students from Princeton, Humboldt, and NUS participated in the Summer University. Currently, *Bernasek* is spending an extended visit at the IRIS institute at Humboldt University, as the KOSMOS Fellow while on sabbatical during the spring term of 2015.

3. Proposed Activities in the Planned Exchange Program

At the heart of the Humboldt-Princeton Exchange Program in Novel Opto-Electronic Materials is the exchange of students, postdocs and faculty in order to strengthen the direct collaboration in research and training.

3.1 Exchange for Enhancing Research

All participants of the current proposal are involved in research projects, funded from different sources, and focusing on Novel Opto-Electronic Materials, as described above. However, there are particular strengths on both sides: Besides faculty of chemistry (*Bernasek, Schwartz, Hecht*), who are involved both at Princeton and Humboldt, Princeton provides also a particular focus on electrical as well as chemical and biological engineering (*Kahn, Rand, Sturm, Wagner, Loo*), and likewise Humboldt has a focus on experimental (*Benson, C. Koch, N. Koch, Rabe*) and theoretical physics (*Draxl, Dzubiella*).

To bring this potential for collaboration to full fruition, we propose to establish a collaboration enabling fund, which will be made available to the involved faculty, young researchers and graduate as well as undergraduate students, by application to a three person steering committee at each institution (*Rand, Bernasek, Kahn* at Princeton, *Rabe, N. Koch, Hecht* at Humboldt). This collaboration enabling fund will facilitate visits of researchers at all levels between the partner institutions for various lengths of time. This will enable working together directly on research projects, and in collaboration, lead to new research ideas. The typical duration of these exchange visits are expected to be between a few weeks and a few months. The current proposal requests resources to establish this collaboration fund for the upcoming two academic years, as outlined in the budget.

A strong focus of the work of the collaboration to be accomplished in the coming two year period is to use the experience gained in our work together to aggressively seek funding for our ongoing collaboration outside of the Humboldt-Princeton Strategic Partnership. We propose to use some of the funding to support a short visit of two of the Humboldt researchers to Princeton in the late summer of 2015 to finalize preparation and submission of a pre-proposal to the NSF for the PIRE program. (www.nsf.gov/funding/pgm_summ.jsp?pims_id=505038)

This preliminary proposal is due in mid-October, and if successful, a full proposal will be invited in January of 2016. The preparation of the preliminary proposal is crucial to this funding request, thus the need for an in person meeting to complete preparation of this document. The full proposal will be due to the NSF in May of 2016.

A final aspect of the activities planned for support in the proposed project period is a planned international workshop on Novel Opto-Electronic Materials, which will be held in Singapore in conjunction with the International Conference on Electronic Materials, June 26 to July 1, 2016. The workshop is planned for the three days following the main meeting, and will involve faculty and student collaborators from Princeton University and Humboldt Universität, along with our collaborators from the National University of Singapore, presenting and discussing the results of our collaborative studies at a point midway through the two year requested funding period.

In addition to the targeted PIRE program supported jointly by NSF and DFG, there are a number of other programs suitable to provide additional outside support of this research exchange program on Novel Opto-Electronic Materials. Programs of the Alexander von Humboldt Foundation, including the Humboldt Research Fellowships for Postdoctoral Researchers and also for Experienced Researchers, which allow visits for more than six months, will be pursued. It is expected that the shorter visits funded through the current Humboldt-Princeton Strategic Partnership will improve the quality of the proposals to the Humboldt Foundation, and thereby

their chances of being successful. At a more advanced level the Humboldt Foundation also provides various Awards, such as the Sofja Kovalevskaja Award for successful top-flight junior researchers, who may use the award to spend five years carrying out research of their own choice in Berlin, as well as the Friedrich Wilhelm Bessel and the Fraunhofer-Bessel Research Award for academics, who have already gained international recognition in their fields. These awards provide the funding to spend 6 to 12 months of time in Berlin. Again, work during the funding period of the current proposal aims at identifying and developing suitable projects for funding by these awards.

The NSF encourages requests for supplements to existing research awards to facilitate international cooperation. These avenues of support will be pursued by the participants with active research awards from NSF in the area of the Exchange Program. The NSF Division of Materials Research supported MRSEC at Princeton University may also be an avenue for modest continued support of our international collaboration. Again, the NSF encourages this sort of international cooperation, and several of the participants in our collaboration (*Schwartz*, *Kahn*, *Loo*) are involved in the MRSEC as well

We plan to explore all these possibilities for continued support of the international collaborative aspects of our interactions, focused on enabling our continued research collaborations.

3.2 Exchange for Enhancing Teaching

An additional important goal of this overall program is to enhance both graduate and undergraduate teaching through the exchange of students and faculty.

For the graduate student teaching, sustainable funding will be provided in the long run through a successful proposal for an International Research and Training Group (IRTG) on *Novel Materials for Efficient Energy Generation and Information Technologies*, to be funded jointly by the National Science Foundation (NSF) and the Deutsche Forschungsgemeinschaft (DFG) for at least 9 years.
(http://www.dfg.de/en/research_funding/programmes/coordinated_programmes/research_training_groups/in_brief/index.html for program details).

In order to be successful with this application it will be necessary to demonstrate our well established interactions. Along these lines, Humboldt-Universität, with funds from its *Strategy for the Future* within the German Excellence Initiative, together with the Helmholtz-Zentrum für Materialien und Energie in Berlin, has initiated funding in the academic year 2014, for the support of graduate students for an initial phase of three years within a Graduate School devoted to this topic. Princeton faculty will participate within the project proposed here to join

this Graduate School (Chairmen: participating PIs *N. Koch* & *Dzubiella*), teaching pertinent graduate courses. It is expected that this experience will improve the quality and thereby the chances of success of the application for an IRTG.

Likewise Humboldt Faculty will continue to participate in Princeton University Graduate Courses, since the mutual experience of the faculty in graduate education will enhance the success of the planned IRTG. As noted earlier, *Rabe* taught a graduate course jointly with Princeton faculty in chemistry in the 2014 spring term at Princeton.

The exchange of graduate students is also essential, allowing them to carry out certain parts of their thesis work in collaborators' laboratories. First successful examples are seen in the collaboration between *Kahn* and *N. Koch*, whose graduate students have participated in research in laboratories both in Princeton and Berlin, with further exchanges underway. Additionally, a graduate student in the *Bernasek* group is scheduled to visit the *Rabe* laboratory in Berlin this fall as part of their ongoing collaboration.

Advanced undergraduate students will be also incorporated into the exchange program, e.g., to carry out research on their senior thesis and with summer internships. Short term visits and summer internship visits by undergraduates would be supported by the collaboration enabling fund we propose. We also plan to work to establish a formal undergraduate student exchange program between Humboldt-Universität and Princeton University. This would allow highly qualified Humboldt and Princeton students to study a semester or year abroad at the respective partner university, and obtain credit toward their respective degree programs. By providing attractive study opportunities for the partner students, the respective host university prepares the ground for a permanent mutual exchange. This includes mutual agreements on credit-transfer regulations as well as the development of shared curricula. The funding of long-term international study and training partnerships (Internationale Studien- und Ausbildungspartnerschaften = ISAP) are possible through the German Academic Exchange Service (Deutscher Akademischer Austauschdienst = DAAD).