Serendipity and the quest for new materials — Eric Mazur
Address given at the 2012 STS Forum in Kyoto (Audio)

Throughout history, the development of new materials and serendipity — we heard the word already mentioned once — have been tightly interwoven. So I believe we should therefore have a little chat about serendipity. I will start with a little anecdote from my own experience and then generalize.

In the mid 1990's my group at Harvard was researching the interaction of very short laser pulses with platinum, a catalyst — basically we were interested in observing the birth of a CO_2 molecule with light. After several funding cycles I started to get worried that the funding agency would no longer renew our contract if I submitted yet another proposal on platinum and carbon monoxide catalysis, but I didn't have any brilliant other ideas. So I basically ended up writing another proposal on the same subject, but towards the end I felt compelled to add a few sentences that we would investigate other materials, including semiconductors. I had no idea what we would do, but it felt like a good idea to put it down.

We were funded and the program monitor made sure that he called me and said "I'm especially interested in the research on semiconductor surfaces." We got the money and of course we continued to do research on platinum and carbon monoxide for two out of the three years. But as the last year started, I started to get really nervous because I knew for sure that I couldn't repeat this a third time. So I called up the graduate student in the lab and I said to him "Look, we really need to do something with semiconductors."

He rummaged around the lab and found a box of silicon wafers that had been used for a completely different experiment and quickly identified them as semiconductors. And realizing it wouldn't be very interesting to look at carbon monoxide on a silicon surface, he rummaged around in our gas cabinet and found a little lecture bottle of gas — sulfur hexafluoride — that I had used when I was a postdoc at Harvard University. Little did he know that sulfur hexaflouride is an extremely stable molecule.

He put it in the chamber, evacuated the air, put in sulfur hexaflouride, irradiated the sample with a femtosecond laser and then called me to tell me the sample turned completely black — very, very black. In fact I brought a little sample, I'm happy to pass it around here, in case you want to have a look at what black silicon looks like.

Well, we put it under a microscope, and it still looked black. Then we put it under the electron microscope and we found out the surface was very structured. It had spikes on the nanoscale, which serve to trap the light in the visible, which gives it its black appearance in the visible. But very quickly, it turned out there were other surprises. Glass, for example, which is silicon oxide, is transparent in the visible, silicon is transparent in infrared. If you take glass and etch it, the surface becomes rough, but it's still transparent. It turned out that black silicon was no longer transparent in the infrared because the electronic properties of the silicon had completely changed.

Well, ten years later, several patents later, in fact many patents, and now a whole host of groups doing research in the same area, it turns out that its actually a new class of material, a semiconductor with an intermediate band. And, I'm happy to say, that there is now a company that is commercializing this material for imaging devices. In addition, there are many other opportunities. It turns out — this is worked on by another group — that the structures at the surface can be used to transfect cells, get genetic materials into the cell, because of the asperities on the surface. Likewise, the same technique can be used to create an intermediate band in titanium dioxide, a catalyst that is used for water splitting.

Let me move from silicon to graphene. Several of the previous speakers already mentioned it — a single layer of carbon atoms. The invention of graphene is remarkable for two reasons. The first one is that it's nanotechnology on a "nanobudget." The way it was discovered was simply by putting graphite onto Scotch™ tape and then, by putting two pieces of Scotch™ tape together, separating — peeling off, if you want — the single layers of graphene. The other remarkable fact is that the researcher who is responsible for it, Andre Geim, not only won the Nobel Prize in 2010 for this invention, but also won the IgNobel Prize ten years earlier. Now, for those of you who don't know what the IgNobel Prize is, it's a prize that is awarded every year on my campus, and its given for science that makes you laugh at first and think thereafter. If you want to have some fun, look at the last few years of prizes, you'll laugh first, but you'll think thereafter. Now, Andre Geim, won the IgNobel Prize for levitating a frog. I'm not making that up, he actually managed to levitate a frog.

Now its very informative to read the interview on the Nobel website with Andre Geim, where he basically says that the invention of graphene, as well as the levitation of the frog, resulted from what he calls a "Friday night experiment," where he pushes his graduate students to take whatever lies around in the lab and to try to come up with something completely new. Of course, in most of the cases these things end up in failures, but sometimes they'll get you an Ig Nobel Prize and sometimes they'll even get you a Nobel Prize.

So I'd like to pose the question, how can we incubate such innovation? Innovation in research and of course, innovation in materials. Now, while I'm not sure that I can give you the answer to this question, I can at least offer you some food for thought. There's no question that every politician, every research agency, every researcher, hunkers for transformational advances, and disruptive innovations. Serendipity, however, is difficult to promote because of two reasons: resistance to change and intolerance for failures. Consider semiconductors, for example. There's no doubt that the modern age is shaped by advances in semiconductors. In the early part of the twentieth century, however, most solid state physicists ridiculed the field of semiconductor physics as *schmutzphysik,* which is German for "dirt physics." Because it was hard to control the impurity concentration in the growing of semiconductors — which is precisely which gives them the interesting properties — research in this area was often called research with irreproducible results. No physicist worth his salt ought to venture in such a field. The irreproducible results, however, eventually led to the microelectronics and information revolutions of the late twentieth century.

In addition to resistance we have to deal with the failures that inevitably accompany innovation. I think no funding agency likes to bet on random Friday night experiments and research that is not already viable is unlikely to be funded. Neither our approach to education nor our research funding policies reward or even tolerate failures and unfortunately the road to innovation is littered with failure. So, unless we provide an incentive for risk taking and accept unsuccessful attempts as a necessary price of serendipity, it will be hard to promote innovation.

Maybe it is time that we pay more attention to the IgNobel Prize winners.