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75 Years of the Device Research Conference—A History Worth Repeating

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ABSTRACT At a time when the scientific community is overrun with conferences, workshops, and congresses to discuss all facets of innovation, much can be learned from considering a meeting that has withstood the test of time: the Device Research Conference (DRC). The DRC has been the launching pad for many game-changing innovations, from early transistors to new electronic materials. While the conference has undergone transformations to adapt to changing times, it remains true to its roots in a way that has enabled 75 years' worth of successful technical gatherings. Remembering DRC's past provides inspiration for preserving and, we would argue, repeating the pattern laid by this historic meeting.

INDEX TERMS Electron device research, transistor, MOSFET, HEMT, epitaxy, nanomaterial, nanoelectronics, optoelectronics, conferences.

I. INTRODUCTION

Take a quick glance around at the electronic devices that are part of your everyday life: computers, smartphones, tablets, ultrathin displays, smart appliances, etc. Dissecting any one of them would reveal critical technologies with a common theme in their genesis story: they were first presented, debated, transformed, or even conceived at a meeting of the Device Research Conference (DRC). From the first transistors to the technology behind lasers and light-emitting diodes, the DRC has been a hotbed for launching the innovations in electronic and photonic devices that drive today's information age.

Following on the heels of the development of quantum mechanics and the solid-state physics of semiconductors, for the past 75 years, in the early part of summer, the DRC has been an annual gathering of the foremost researchers in the field of electron devices. This gathering rotated its venue throughout the United States, changing its location but never changing its surroundings—a university campus has always been the home for the DRC. This meeting has a history that is decorated with "firsts" and is legendary for engendering frank discussions and debates. On this semi-sesquicentennial year, much can be learned by glancing back at the DRC's rich history. This reflection is not just valuable for deepening our appreciation for how we arrived at the present, but also provides inspiration for preserving and, we would argue, *repeating* the pattern laid by this historic meeting. And perhaps, this history provides a window to glimpse tomorrow's opportunities.

We now live at a time when the scientific world is veritably littered with technical conferences / symposia / workshops / congresses. It is ever more important to consider the meetings that have withstood the test of time; including how and why they were able to do so. Throughout its history, the DRC has been the launching pad for many game-changing device innovations. And yet, it has never been just about what was presented at the meeting but also about the interactions among attendees, collaborators and competitors alike. The engaging and often intense debates that occurred during and between scientific talks and, most memorably, in the rowdy rump sessions, offer a freedom of expression in scientific discourse that is widely coveted and rarely achieved in similar venues. A large fraction of participants are young students whose contributions are actively encouraged, giving

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them a baptism by fire, so to speak. While the conference has undergone its share of transformations to adapt to changing times, it remains true to its roots in a way that has enabled 75 years' worth of successful technical gatherings.

II. THE LAUNCHING PAD

It is fitting that an academic environment has always served as the backdrop for the DRC. From its inception, this meeting has been a "crucible for fresh ideas" [1], and even referred to as an "invisible college" [2] to educate researchers in the field on the latest in electron devices. DRC was the first and only conference of its kind and started with the name, "Conference on Electron Device Research" or CEDR [2], known by those who attended as "the Tube Conference" owing to the focus on electron tubes [3] in the early days. This was when electrons were moved ballistically through vacuum tubes and the exploration of solid-state materials for electronics was in its infancy with an uncertain future. In fact, when Bardeen, Brattain, and Shockley were able to observe a comparable effect by moving electrons through a solid-state semiconductor material, the first place they presented their device was at the CEDR [4]. This work was presented as a technical discussion about the transistor by William Shockley at the 1948 CEDR held at Cornell University.

As work on solid-state devices caught hold, some researchers split from the CEDR to start the Solid-State Device Research Conference (SSDRC) in the early 1950's [3]. However, the separation proved temporary, and under the leadership of Herbert Kroemer and Calvin Quate the CEDR and SSDRC merged to form the DRC with the first meeting held in 1969 in Rochester. Even while existing as two separate meetings (CEDR and SSDRC), the conference maintained its unique attributes of first-seen research results, university settings, and rowdy rump sessions.

While uncovering details about DRC's history, one thing becomes very clear: there's hardly a DRC attendee, young or old, who does not have fond memories or anecdotes of learning about some exciting new results at a past DRC (especially for those who were heavily involved in the conference from the 1960s–1990s). Perhaps what is most challenging is identifying all the discoveries that received first light at these annual gatherings. An attempt at a comprehensive list would undoubtedly prove to be lacking. Here are a few of the historic "firsts" that come up most frequently from the conference's "Old Timers" (for the 1940s–1970s):

- Transistor device presented for the first time by William Shockley (1948, Cornell University) [2].
- First presentation of diffusion techniques for incorporating impurities in germanium and silicon by Bell Labs researchers (1955, Carnegie Institute) [4].
- One month after filing a patent, Dawon Kahng and John Atalla present the first successful (and practical) field-effect transistor using a metal-oxide-semiconductor (MOS) structure with silicon (1960, Carnegie Institute) [5], [6].
- First presentation of a lattice-matched heterojunction by Jerry Woodall and IBM colleagues, beginning the revolution of countless heterojunction device technologies (1967, University of California – Santa Barbara).
- Presentations on the first dynamic random-access memory (DRAM), development of room temperature semiconductor lasers, and the first charge-coupled device (CCD), all in the same DRC meeting that is known as "a particularly memorable one" [4] (1970, University of Washington).
- Inception of the idea for the high electron mobility transistor (HEMT) by Takashi Mimura, with presentation the following year with colleagues from Fujitsu (1979, University of Colorado).

What was it that fueled such a hotbed for first reports and discoveries being presented at DRC? Part of the answer may be found in the invitation-only, closed-door nature of the meetings held for the first several decades. The density of idea sharing that occurred at the meeting is best illustrated by Charles Süsskind who, at the conference's 25th anniversary, noted that, "[DRC] is the conference to which other laboratories send people to find out what is going on at BTL (Bell Telephone Laboratories). Bell engineers modestly retort that it is, on the contrary, the conference to which BTL sends a platoon to find out what is going on at other laboratories. Participants listening to one Bell engineer questioning another after his paper has been presented have sometimes wondered if this was not the conference to which giant BTL sends its engineers to find out what was going on at BTL" [2].

As highlighted in Fig. 1, DRC's launching pad status has continued throughout its 75 years. The 1980s brought countless new heterojunction-based electronic and photonic devices at the DRC. In the 1990s, DRC continued this trend along with new transistor structures for addressing scaling and power challenges. Throughout the 2000s, the DRC remained the platform for many firsts in the quickly growing area of nanomaterial-based electronics, from carbon nanotubes to graphene to countless other two-dimensional crystals.

III. THE INTERACTIONS

In addition to the legendary first reports that decorate the DRC's history, there are countless stories of interactions among meeting attendees that were deeply impactful at both personal and intellectual levels. At the 50th DRC in 1992 (held at the Massachusetts Institute of Technology), plenary speakers shared their reflections on the first half-century of the meeting. Chapin Cutler recalled his attendance at the first DRC (CEDR at the time): "I was in awe of these great men (presenters at the first meeting) and felt privileged to hear, and even touch some of them. I did not realize how privileged I was to share the back row with the creators (to be) of the new 'Electronics,' to share a pew with the future winners of Nobel prizes; the IEEE Medals of honor, Edison medals, Presidential Citations, etc.; the creators and

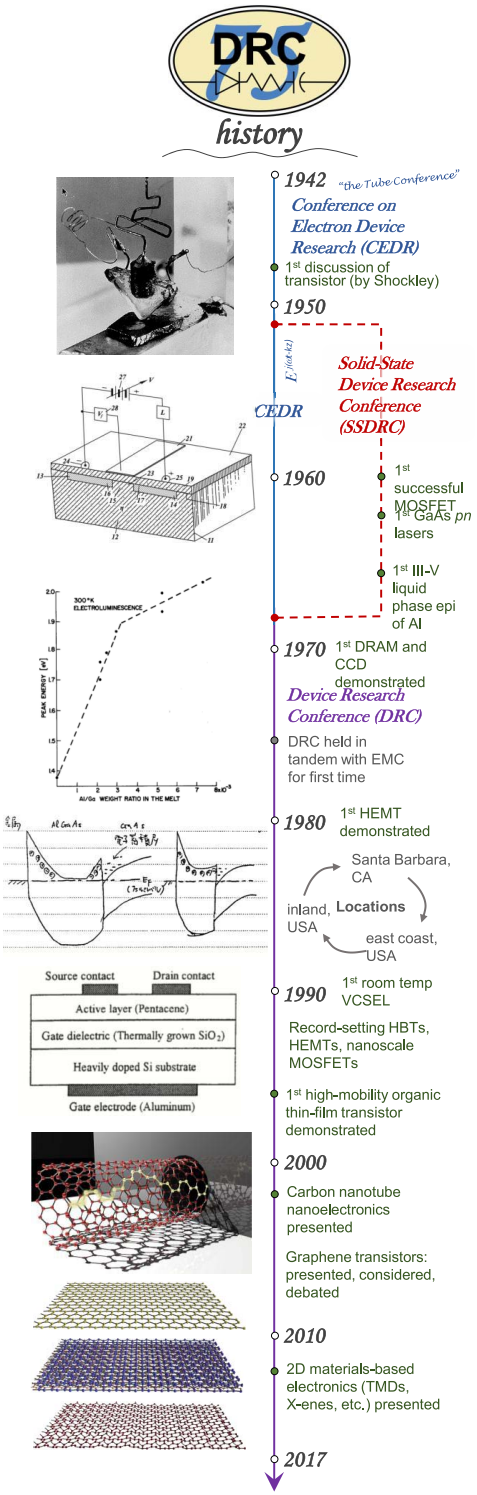

FIGURE 1. Timeline of major events and developments presented at the DRC over its 75-year history. Images are of the first transistor, patent for the first Si MOSFET, evidence for epitaxial growth of III-V layers, conceptualization of the first HEMT, structure of an early organic TFT device, and structures of nanomaterials (carbon nanotube, graphene, and other 2D crystals) explored for new electronic devices.

leaders of some of the world's greatest industries. I had no idea of the stature of my colleagues. Take note, young men and women: the great leaders of the 21st century are in the back seats, with you. Doubtless, one of these great leaders is YOU" [1]. This observation remains as true now as when it was made 25 years ago; many of today's leaders in device research were likewise schooled by the annual summer gathering that is now in its 75th year.

Many great ideas have their roots in the discussions held at a DRC. One example is from Takashi Mimura who presented his work on depletion-type GaAs MOSFETs at the 1979 DRC held at the University of Colorado. He recalls, "While talking with a conference attendee immediately after my presentation at the conference, I was suddenly seized by the will to look for ways to control electrons accumulated in the superlattice. Although I cannot exactly explain this unexpected change of direction, it probably came about because I had wanted to research more feasible subjects than GaAs MOSFETs" [7]. Two months later, Dr. Mimura filed a patent for the high electron mobility transistor (HEMT), which is critical to virtually all modern communications technologies, among many other applications.

Beyond the historical nostalgia is a very real pattern for excitement and opportunity among attendees of the DRC. While current attendees mark the 3rd or 4th generation of device researchers, the same thrill shared by the 1st generation attendees persists. Today's students are still awed by the opportunity to interact with the big names in the field, game-changing results are still eagerly received and debated, and new ideas are still germinated in the university environments that maintain the conference.

IV. TRANSFORMATIONS

To survive the technological revolution, including all that it has affected in scientific research, has required some adaptation by the DRC. Such changes are not necessarily negative, but they do lead to a certain degree of transformation. Indeed, change is necessary for survival. There are three main transformative events that have occurred for the DRC over the years: 1) open attendance, 2) tandem involvement with the Electronic Materials Conference (EMC), and 3) publication of a digest.

1) Open attendance. Part of what made the early DRC gatherings so special for some attendees was simply having received a coveted invitation to attend! Early meetings would bring together a few hundred attendees (surging in some instances to nearly 1,000), all by invitation-only. There was rarely even a published agenda and no press involvement. Some have noted that "because of this, the Conference was widely perceived as a forum for the exchange of novel ideas, research results, and hot topics. It was not 'publication,' in the sense of patent law" [1]. It is difficult to determine precisely when the DRC transformed from invitation-only to open-invitation, but it is likely that this occurred gradually and related to a lag in attendance. Most probably, the change happened in the 1970s.

2) Tandem involvement with the Electronic Materials Conference (EMC). To this day, one of the greatest "friendly competitor" conference to the DRC is the International

Electron Devices Meeting (IEDM). IEDM held its 63rd meeting in 2017 and has a rich and respectable history of its own. A key defining difference between the DRC and IEDM in the 1970s was that the IEDM specifically embraced the rising silicon industry, with most sessions focusing on technology-driven research results and less on exploratory, first-seen device results. As attendance at DRC continued to drop through the early 1970s, organizers recognized an opportunity to strengthen the natural connection held between device and materials researchers. As such, "in part to raise attendance, the 1976 DRC in Salt Lake City was held in tandem with the Electronic Materials Conference . . . attendance revived and once again began hitting traditional levels of about 500 by the end of the decade" [4]. To this day, DRC has been held in tandem with the EMC and the relationship between the device and materials fields retains a strong complimentary link at both meetings.

3) Publication of a digest. As noted above, the first 25-30 years of the DRC was by invitation-only and was a closed-door meeting, absent of the press. About a decade after opening attendance, the DRC began publishing its abstracts. At first, this was simply the inclusion of short abstracts (1-2 paragraphs) from each presentation, published in one of the Fall issues of the IEEE TRANSACTIONS ON ELECTRON DEVICES. In 1991, for the 49th DRC, the conference moved to a dedicated digest published by the IEEE, with each "abstract" consisting of one page of text and one page of figures or other supporting material. For the past 26 years, these published abstracts have been indexed (citable) and make DRC one of the few technical meetings requiring such intensive work to be shown for contributed abstracts to be considered for acceptance.

V. A HISTORY WORTH REPEATING

While it is clear that there are notable differences between the 1st and the 75th DRCs, there are also roots that have been carefully preserved despite the transformations. While we no longer close the doors for discussions among the select elite in the field, active and intense discussions are still nurtured and encouraged at each DRC; but now these instructive debates are open to all, including students, who are strongly encouraged to participate. Our tandem involvement with the EMC since 1976 has proven to be prescient based on the now critical fusion of the respective fields in the study of nanomaterial-based and/or quantum devices. And, the accessibility of abstracts presented at 1/3 of the 75 DRCs is thanks to the decision to publish a digest in 1991.

But not all has changed. DRC continues to stimulate rowdy rump sessions. Active and inspiring conversations still dot the hallways. The surroundings remain those of a University, preserving the unique element of collegiate learning. Some of the greatest, first-seen results in device research are still shared, debated, and disseminated each June.

For device researchers who have "grown up" in the scientific environment of the 21st century (present authors included), it can be difficult to appreciate how such a volume of discoveries and richness of history could come out of one conference. As of the writing of this piece, there are no less than 40 meetings held throughout the world that involve device research as a core part of their focus. At a time when we are overrun with such technical meetings—far too many to keep up with—we recommend returning to the conference where it all began. For electron devices, the roots are deep and strong in the DRC; a meeting with a history worth repeating. And, should we be successful in doing so, perhaps the technology that drives the gadgets the future–10, 25, 50, or even 75 years from now – will be able to cite the same commonality in their origin: The Device Research Conference.

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