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# CRYOCOOLERS 21

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# Preface

The objective of *Cryocoolers 21* is to archive the latest developments and performance measurements in the field of cryocoolers by drawing upon the work of leading international experts. In particular, this book is based on the 62 peer reviewed manuscripts that were prepared for the 21st International Cryocooler Conference (ICC21) held as an all-virtual conference on December 7-10, 2020. Because of the 2020 corona-virus epidemic that emerged in March 2020, the original Orlando, Florida venue of ICC21 had to be delayed and eventually reformatted into the all-virtual venue in December 2020. This led to some papers of the original February 2020 Call being withdrawn, while others were added in a supplementary Call for Papers that was held in September 2020. A total of 161 cryocooler followers and researchers from around the world participated in the virtual conference, and 71 authors contributed slides and movies on the ICC website for viewing during the conference. Of those, 62 are captured here as formal manuscripts.

A second change introduced with ICC21 was the award of an Exceptional Service Award (actually two awards this conference), and a Best Student Paper Award. These are expected to be continued in future ICC conferences and are highlighted in the Awards pages directly following this *Preface.*

As with past conferences, following the book's publication, digital versions of all of the ICC21 papers will be available under the ICC website's Past Proceedings tab. This tab similarly provides access to digital copies (PDFs) of all ICC papers published since the first conference in 1980.

Because the book's contents are designed for users of cryocoolers as much as for developers of cryocoolers, extra effort has been made to provide a thorough Subject Index that covers the referenced cryocoolers by type and manufacturer's name, as well as by the scientific or engineering subject matter. Contributing organizations are also listed in the Subject Index to assist in finding the work of a known institution, laboratory, or manufacturer. To aide those attempting to locate a particular contributor's work, a separate Author Index is provided, listing all authors and coauthors.

The content of *Cryocoolers 21* is organized into 13 chapters, covering the various types of cryocoolers and their applications. At the beginning are two chapters covering important recent applications of cryocoolers in the aerospace, commercial and scientific arenas. These articles contain particularly useful information for the potential user of cryocoolers as well as for the developer. Next, is a short chapter on two cryocooler integration technologies, mainly fluid loops and flex braids for coupling cryocoolers to both nearby and remote loads. Following this chapter is a sequence of chapters on Pulse Tube and Stirling cooler development and performance investigations, including recent research on external phase shifters and linear compressors and their drive electronics for these regenerative cryocoolers.

Following the chapters on regenerative cryocooler technologies, are three final chapters covering recuperative cryocoolers—Brayton and Joule-Thomson—and low-temperature sub-Kelvin cryocoolers. Sub-Kelvin applications include space bolometers and x-ray sensors, and ground-based sensors in materials research, and scanning tunneling microscopy (STM).

In reviewing the contributions contained in *Cryocoolers 21*, we note the continued strong interest in the development of pulse tube cryocoolers for a growing variety of long-life, high-reliability

cryocooler applications. A recent thrust in this area is examination of the use of active phase shifters to further improve pulse tube thermodynamic efficiency.

Also of note, is the significant number of very small (microcoolers) and some very large (multi-kilowatt coolers) entering the marketplace...these expand the available operating capacity range to over three orders of magnitude!

Example applications of cryocoolers include sensors for tiny CubeSat satellites, space infrared sensors for large space instruments, precooling for cryogen-free sub-Kelvin applications, cooling of HTS and LTS superconducting magnets and electronics, and helium and hydrogen liquefaction and control of cryogen boil-off.

In summary, it is hoped that this book will serve as a valuable source of reference to all those faced with the challenges of taking advantage of the enabling physics of cryogenics temperatures. The expanding availability of low-cost, reliable cryocoolers continues to enable major advances in a number of fields.

*The Editors*