Automatic Diameter Control Software

Overview

This document describes a commercially available Automatic Diameter Control (ADC) program that has been developed over twenty years. It is based on the expertise and knowledge of Dr. Frank J. Bruni, who has nearly 40 years' experience in the growth of oxide and semiconductor crystals (see www.FrankBruni.com).

The software is designed to be fitted to a Czochralski crystal growth system. It controls the diameter of the growing crystal by measuring the weight of the crystal. The growth rate of the crystal is calculated by taking the first derivative of the weight versus time, dW/dt. This variable is used to calculate the diameter of the crystal.

The diameter is compared to a desired diameter, which is calculated from the geometric shape of the crystal. The difference between the measured diameter and the desired diameter is the diameter error. This variable is used in a PID (Proportional, Integral, Derivative) feedback algorithm to control the temperature of the crucible.

The software runs on a standard PC using a Windows operating system. It has a graphical user interface providing the operator with a great deal of real-time data on several parameters, which is extremely useful for tracking the precision of control and identifying problems with the equipment.

The ADC program logs data to the computer's hard drive continuously during the growth process. This data is stored in an Excel file format which makes it very easy to analyze after the growth of the crystal. The data can be copied from the computer while the crystal is growing so that the operator can monitor and graph process variables separately from the actual crystal growth system.

In addition, the program has the ability to take snapshots of special data arrays that provide the user with a fine scale record of process variables seconds or milliseconds apart.

Hardware requirements:

Figure 1 below shows the recommended hardware layout for the ADC program.

Computer requirements:

The computer should be a standard industrial grade PC running a Windows 98 or newer operating system. COM port communications are achieved using a 4-port, USB to COM port adaptor. The display will be run in the 1024 x 768 pixel resolution. (Note, some newer computers come with display drivers that do not accept this screen resolution, so be careful when ordering.) The computer should have at least one writeable drive such as a floppy disk drive or a CD burner. This is to allow the operator to copy crystal growth

run data to a portable medium for analysis on another computer. However, if it has a USB port (fairly standard these days), a memory stick can be used to remove data.
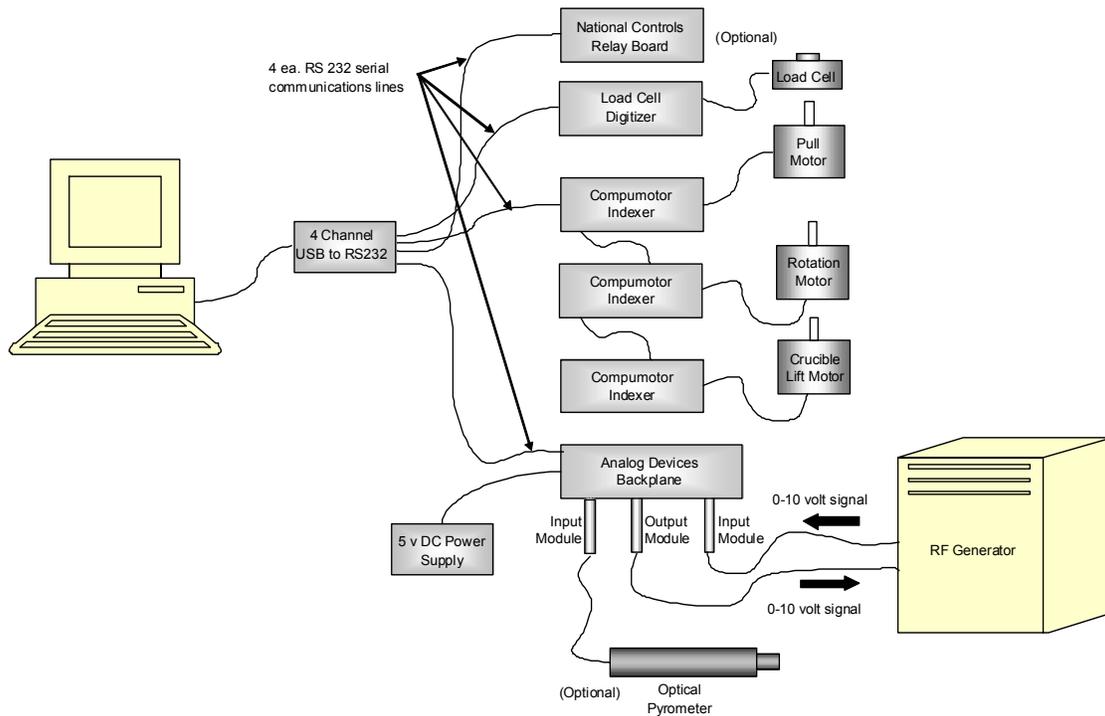

Figure 1

Peripheral hardware:

Communications with all peripheral hardware is through the COM ports configured for RS232 bi-directional communications. The computer does not need COM ports. A USB to COM port adaptor can be used to provide as many COM ports as needed.

Motors:

The program is configured to communicate with Compumotor type 6000 Zeta indexers and the corresponding stepper motors for seed lift, seed rotation and crucible lift. Other motor drivers can be adapted for use with this software.

Analog I/O:

All analog input and output signals are through Analog Devices series 6B modules. The basic configuration of the software requires one analog input signal in the range of 0 – 10 volts from the RF generator. This signal should be roughly proportional to the power output of the generator. The generator output is controlled using a second Analog Devices module with a 0 – 10 volt or 4 - 20 mA output signal. (Note: the same module can be configured for either output.) Additional analog I/O signals can be accommodated using more Analog Devices modules. The program can be configured to record the

output of an optical pyrometer, for example, and/or to monitor the available voltage of a UPS back-up battery stack.

A DC power supply is required to provide current to the analog output module.

Relay Board:

The program will control the relays on a National Controls type R25 dual SPDT relay board. These relays can be used to switch the generator off at the end of the cool-down cycle or to turn on an alarm.

Load Cell:

The ADC program will accept the input from either of two load cell digitizers: a Hardy Instruments HI2151 WC or an Interface Force Measurements model 9840. The Hardy has a display resolution of 6 digits (0 – 999,999) but an internal resolution of only 60,000 counts. The Interface unit has a claimed internal resolution of 24 bits. The limiting factor in the case of both units is probably the load cell. In other words, despite the claimed resolution of the digitizer, the load cell has a given mV/volt response, and to get a true 6 digit precision requires the measurement of microvolts. It is likely that the noise level in the load cell would swamp such fine measurements.

The program will also accept an input from a Sartorius balance. The Sartorius is a true null point instrument and, according to claims by the manufacturer, it has a higher intrinsic resolution than a strain gauge type load cell. The issue becomes one of getting a balance with sufficient range and sufficient resolution in the serial output.

Program Operation

The program is written in LabVIEW and presents the operator with an intuitive, graphical interface. As shown in Figure 2, the program controls the entire sequence of the crystal growth process from Heat-up, equilibration of the melt in the Manual mode, growth of the crystal in the Automatic mode, and the return to room temperature in the Cool-down mode.

Figure 2
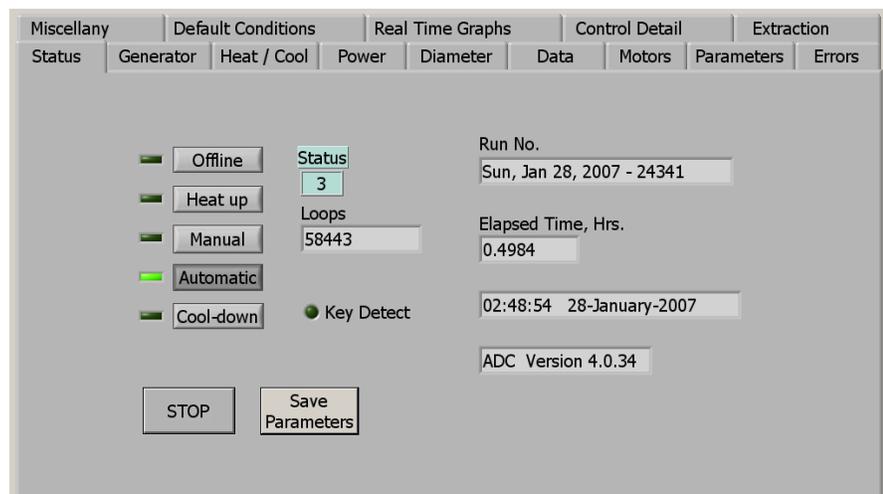
During all stages of the process, the program offers the operator a number of graphical presentations of the growth data (Figure 3). This data is presented in real-time and is graphed versus the elapsed time of the process. It is a very powerful function for showing the user exactly how the process is performing.
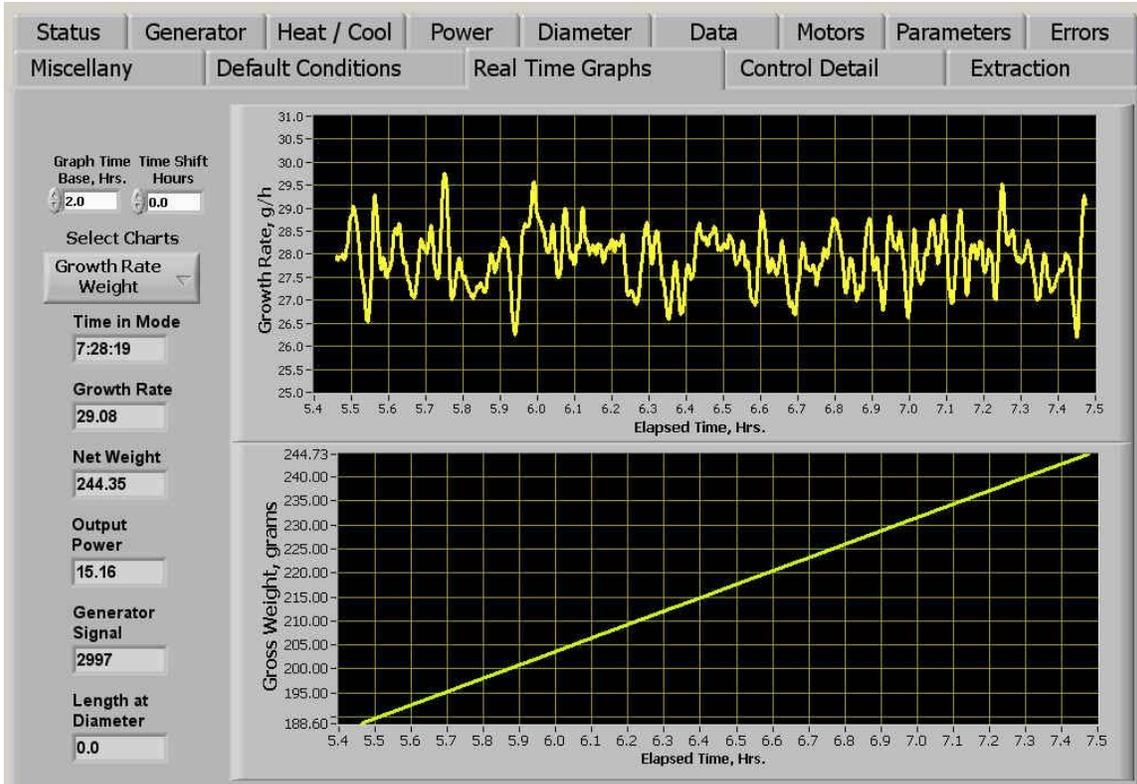

Figure 3. An example of the real-time graphs chart of the ADC program. There are 10 process variables which are presented on 6 real-time graphs that can be individually selected by the user.

Power Control

The regulation of the crucible temperature is the most important control function in the Czochralski process. This ADC program utilizes a cascaded control system as shown schematically in Figure 4. The primary control loop regulates the power going into the crucible from the induction power supply. The setpoint of this control loop is determined by the error in the crystal diameter. This error is calculated by the diameter control algorithm which uses 3-mode, PID (Proportional, Integral, Derivative) feedback gain mathematics to calculate the power correction needed for process control.
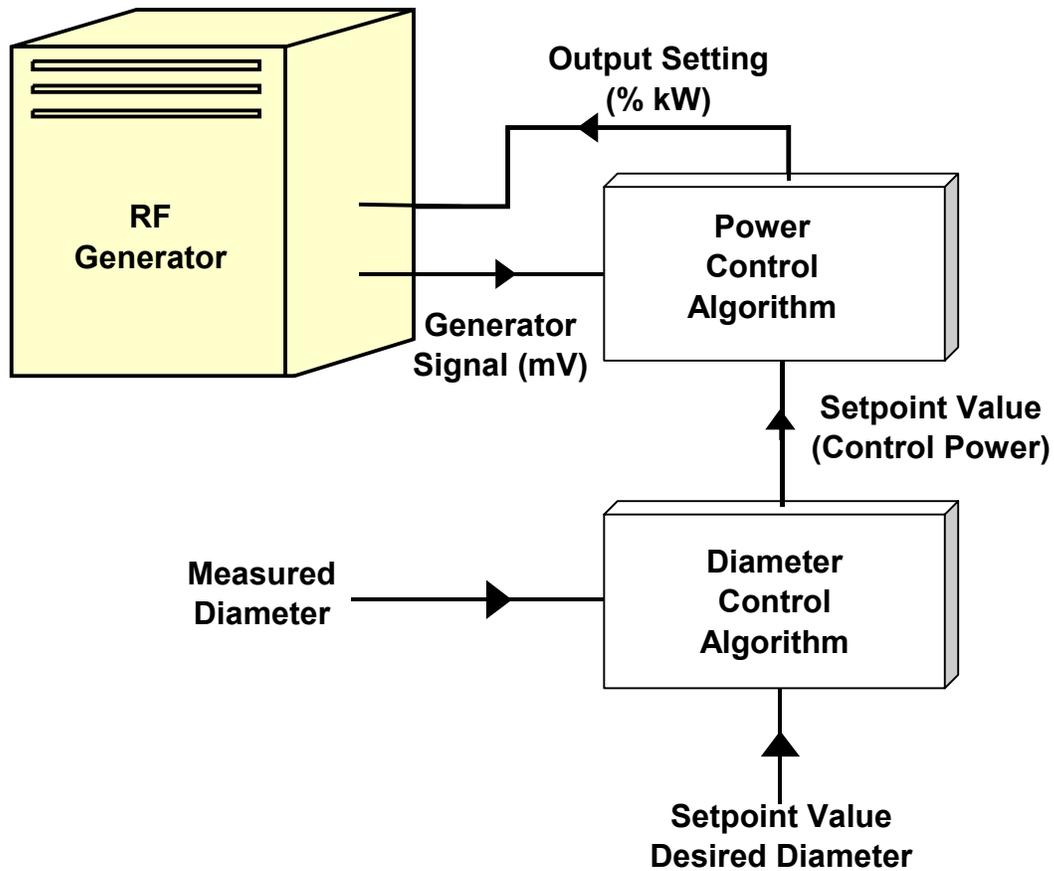
Figure 4. Schematic representation of the cascaded power feedback control scheme.

Control Variables

The program uses up to 64 parameters whose values can be set by the user to tailor operation for any specific material and a wide range of growth conditions (Table 1). The program maintains an historical log of the values of all control parameters on the hard drive including the dates and times changes were made.

Data Collection

The program logs 15 growth variables along with real-time and elapsed time. Data from this log can be used to generate a graphical history of the growth process. Figure 5 shows data from a 100 mm diameter sapphire crystal growth run, and Figure 6 shows the actual crystal corresponding to that data.

| Table 1: The Control Parameters			
1	Seed Dia.	33	Maximum RPM RoC
2	Full Dia.	34	Break Diameter
3	Shoulder Angle	35	Break Length
4	Pull Speed	36	Dwell Time
5	Cruc. Lift Speed	37	Rate Regulator
6	Solid Density	38	History Spacing
7	Liquid Density	39	Generator Gain
8	Crucible Diameter	40	Generator Filter
9	Neck Length	41	Heat-up Start Power
10	Desired Length	42	Base Rate Fraction
11	Tail-off Angle	43	Jerk-out Speed
12	Tail-off Min. Diameter	44	Jerk-out Height
13	Tail Length	45	Cool-Down Profile
14	Proportional Gain	46	Cool Down Rotation Rate
15	Integral Gain	47	Power Drop %
16	Derivative Gain	48	Simulation Indicator
17	Gain Scale Factor	49	Customer ID
18	Weight Scale Factor	50	Pyrometer Filter
19	Weight Filter	51	Pyrometer Gain
20	Diameter Filter	52	Maximum Temperature
21	Data Points in Array	53	Maximum Load Cell
22	Base Rate Time	54	Overshoot Time Base
23	Heat-up Time	55	Overshoot Dead Band
24	Cool-down Time	56	Overshoot Ramp
25	Weight Reading Interval	57	Start Extraction Rate
26	Diameter Update Interval	58	End Extraction Rate
27	Maximum Output Power	59	Extraction Ramp Time
28	Maximum Control Power	60	Additional Extraction
29	Rate Limit mV/hr	61	Crucible Rotation Rate
30	Initial Rotation Rate	62	Not Used
31	Intermediate Rotation Rate	63	Not Used
32	Final Rotation Rate	64	Not Used
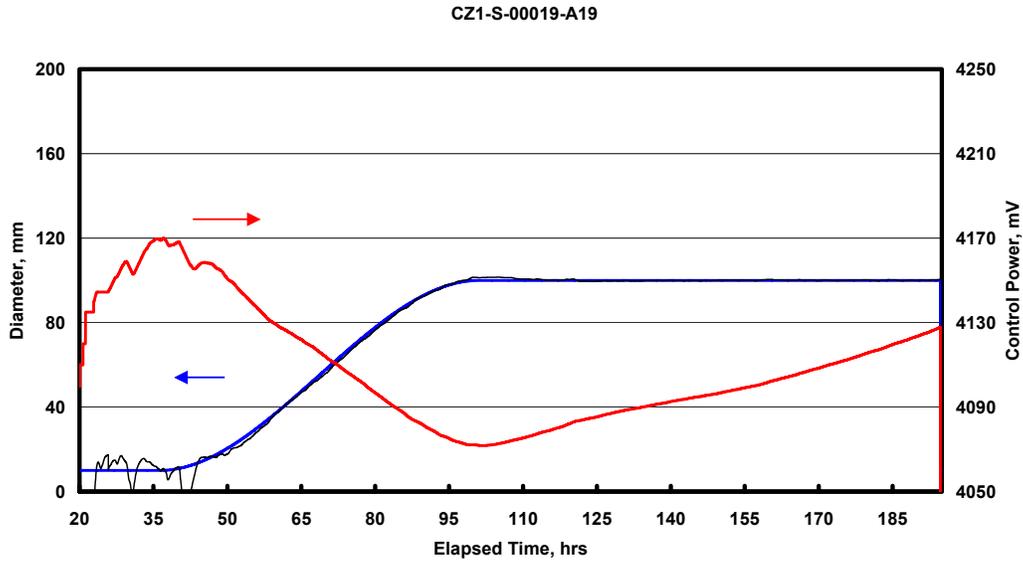
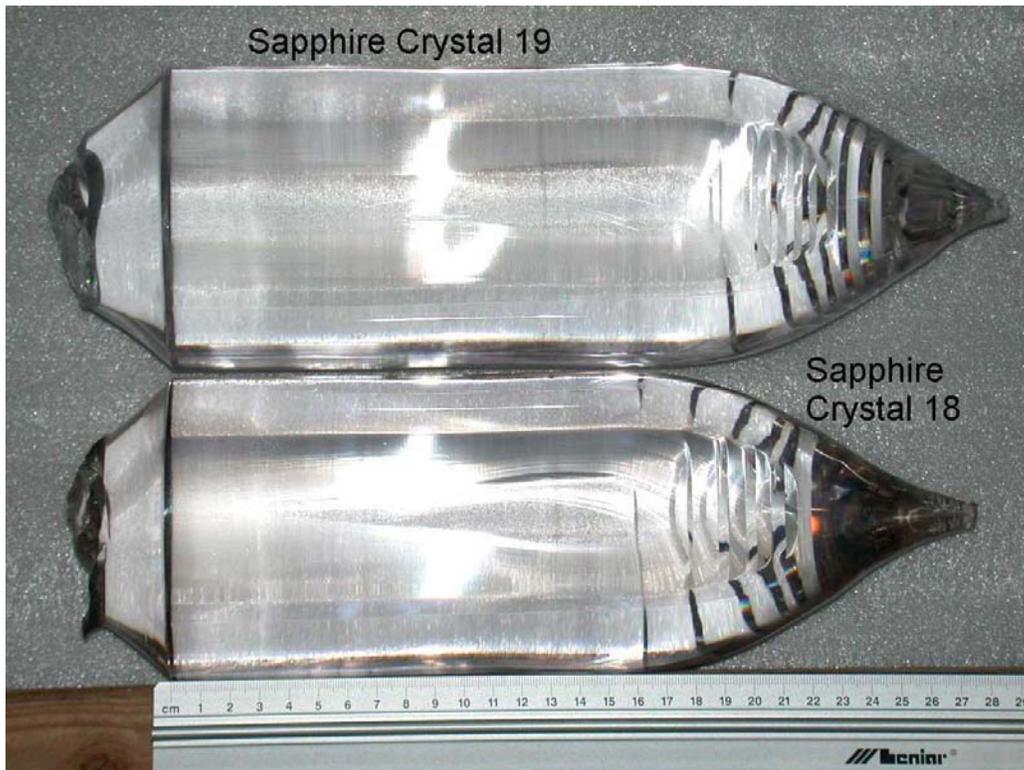Figure 5. Data from the growth of a 100 mm diameter sapphire crystal.

Figure 6. The crystal corresponding to the data shown in Figure 5. It is crystal number 19. The photograph also shows the reproducibility of diameter control that this software can achieve from one crystal to the next. Note: the lines in the shoulder growth area are not diameter variations. They are C-plane facets that naturally form on sapphire crystals.

Program History

The original version of this software was developed in Visual BASIC in 1990. Several systems using the DOS version are still in operation. In 2002 the program was converted to LabVIEW. Table 2 shows a list of companies and organizations currently using this software. Table 3 shows a list of materials that have been grown using this program. Note: because a number of government laboratories and university research centers use this software, not all materials being investigated are included in this list. This software is included on all Czochralski crystal growth systems built by Thermal Technology LLC of Santa Rosa, California (see http://www.thermaltechnologyinc.com/).

Table 2: ADC Software Clients	
Client	**Location**
Ames Research Laboratories	Ames, Iowa
City University of New York	New York, NY
Confidential*	Taiwan
Crystal Technology	Palo Alto, California
Deltronic Crystal Industries	Dover, New Jersey
Honeywell Specialty Materials	Victoria, B.C. Canada
North China Research Institute for Electro-Optics	Beijing, China
Pennsylvania State University	Freeport, Pennsylvania
SAES Getters	Milan, Italy
SAES Opto Materials	Sardinia, Italy
Saint-Gobain Crystals and Detectors**	Washougal, Washington
Sino American Silicon	Taiwan
Thermal Technology, Inc.	Santa Rosa, California
Univeristy of Santiago de Compostela	Santiago, Spain
Universiti Teknologi Malaysia	Johor, Malaysia
*this organization does not wish to have its name disclosed at this time. **formerly Union Carbide Corporation	

Options

The program can be configured to accept the input from an optical pyrometer to monitor crucible temperature during the growth process. It can also control crucible temperature in the Manual mode with a feedback control loop.

The program has been configured to communicate with Eurotherm controllers so that it can grow crystals in multi-zone or single-zone resistance furnaces.

The figures shown below are crystals that have been grown with this software.
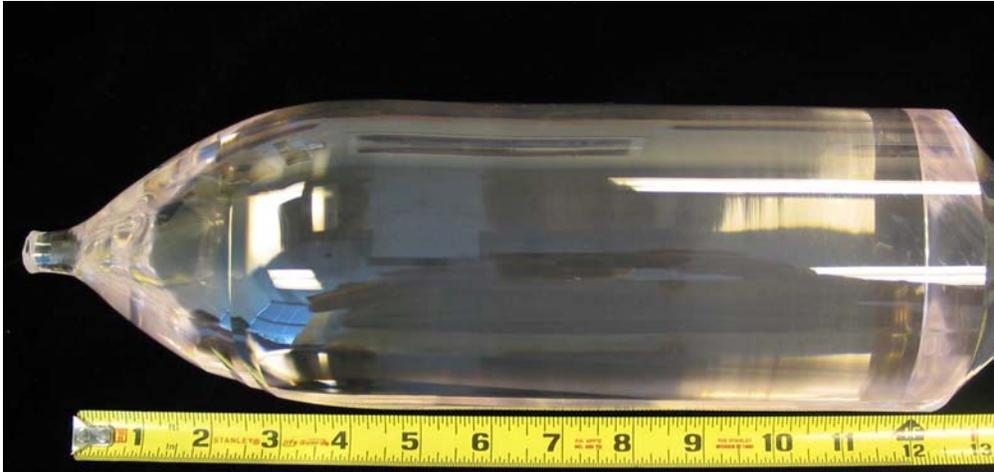
Above: 100 mm diameter sapphire crystal.

Below: lithium niobate. Photo courtesy of SAES Getters, Milan, Italy.

Table 3
Nd:YAG
Sapphire
Lithium Niobate
Lithium Tantalate
Lutetium Orthosilicate
Ca-Zr substituted GGG
Copper

For additional information, please contact:

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