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Spencer E G, Lenzo P V & Ballman A A. Dielectric materials for electrooptic, elastooptic, and ultrasonic device applications. *Proc. IEEE* 55:2074-108, 1967.
[Bell Telephone Laboratories, Inc., Murray Hill, NJ]

Laser communications provided the incentive for an extensive materials research program directed toward the development of crystals capable of low-loss optical transmission and whose properties can be modified by an electric or magnetic field or an applied stress, and whose properties, at the same time, will interact in some specified manner with the optical beam. [The *SCI*® indicates that this paper has been cited in over 95 publications since 1967.]

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"When the first lasers became available, their expected information carrying capacity obviously was of primary importance for the communications industry. Albert Ballman, Pascal Lenzo, and I initiated a program to develop optically transparent crystalline materials that would modulate or modify the optical beam in a predictable manner. The success is shown by the list of materials cited, each of which was chosen as demonstrating a new mechanism or as exemplifying a textbook example of some specific physical phenomenon. Even today, these materials continue to be used in an expanding range of technological applications. This is the reason for the many citations to the paper which also has been reprinted in the book, *Laser Devices and Applications*.[1]

"The lithium tantalate modulator we developed with E.H. Turner was used by R.T. Denton[2] as the basic element in the demonstration by his group of the first high-speed, high-capacity digital optical communications system. When Kurt Nassau[3] discovered the method of poling lithium niobate during growth so that a single ferroelectric domain was formed, it came as a revelation to observe a microwave acoustic pulse train filling the oscilloscope face—at room temperature. The technological implications were obvious. Later, the theory of W.P. Mason and T.B. Bateman[4] explained why the imperfect lithium niobate crystals had lower microwave acoustic loss, at room temperature, than the more perfect quartz crystals.

"Earlier work with Denton and R.C. Chambers using the magnetic garnets, YIG, had opened up the field of microwave ultrasonic technology at room temperature. The niobate devices, however, did not require the sophistication of the garnets, were easy to construct and operate, and cost remarkably little to manufacture. Within a few days of discovering the microwave acoustic properties of lithium niobate, we discovered that the microwave elastooptic values also were higher than any previously known. After an easy to construct elastooptic modulator operating at 1 GHz was demonstrated, a department was formed to exploit acousto-optic technology for communications applications based on these materials.

"Bismuth germanium oxide and the silicon analog are among the very few cubic crystals that have no fourfold axis of symmetry. They are electrooptic, optically active, display both static and moving electric field domains, and display a new phenomenon which we called photoactivity, with which we constructed, with George Moore, an optically activated laser beam switch. Additionally, at 4.2°K, the ultrasonic losses at 1 GHz were the lowest of any known material, being limited only by beam diffraction.

"At the time of our research, KDP was the standard crystal used for modulation of light and required 2,000 V for 100 percent modulation. This was reduced to a few tens of volts using lithium niobate and tantalate and to only one or two volts with strontium barium niobate (SBN). Analogs of SBN, also with the tungsten-bronze structure, subsequently were developed by others.

"What was particularly satisfying to us was the beauty of the overall picture of the science and technology of these crystals as a whole, as well as having the opportunity to carry out basic research in many areas on these materials which resulted in so many useful technological applications."

1. **Spencer E G, Lenzo P V & Ballman A A.** Dielectric materials for electrooptic, elastooptic, and ultrasonic device applications. (Kaminow I P & Siegman A E, eds.) *Laser devices and applications.* New York: IEEE Press, 1973. p. 250-84.
2. **Denton R T, Kinsel T S & Chen F S.** 224 Mc/s optical pulse code modulator. *Proc. IEEE* 54:1472-3, 1966.
3. **Nassau K, Levinstein H J & Loiacono G M.** Ferroelectric lithium niobate II. Preparation of single domain crystals. *J. Phys. Chem. Solids* 27:989-96, 1966.
4. **Mason W P & Bateman T B.** Relation between third order elastic moduli and thermal attenuation of ultrasonic waves in nonconducting and metallic crystals. *J. Acoust. Soc. Amer.* 40:852-62, 1966.