Nonlinear-optical material developments since 2000: characterization, data tables, and best practices

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ABSTRACT

The field of nonlinear optics (NLO) has been continuously growing over the past decades, and several NLO data tables were published before the turn of the century. After the year 2000, there have been major advances in materials science and technology beneficial for NLO research, but a data table providing an overview of the post-2000 developments in NLO has so far been lacking. Here, we introduce a new set of NLO data tables listing a representative collection of experimental works published since 2000 for bulk materials, solvents, 0D-1D-2D materials, metamaterials, fiber waveguiding materials, on-chip waveguiding materials, hybrid waveguiding systems, and THz NLO materials. In addition, we provide a list of best practices for characterizing NLO materials. The presented data tables and best practices form the foundation for a more adequate comparison, interpretation, and practical use of already published NLO parameters and those that will be published in the future.

Keywords: nonlinear-optical materials, data tables, second-order nonlinearity, third-order nonlinearity, best practices

1. INTRODUCTION

Since the pioneering second-harmonic generation experiment of Franken *et al.* in 1961,[1] the research field of NLO has been continuously growing over the years, and so has the number of NLO publications, as illustrated in Figure 1. These publications also include several NLO data tables, all of which were presented before the turn of the century. However, Figure 1 shows that the strongest growth in NLO research output has taken place after the year 2000, and this has been due to major breakthroughs in materials science and technology over the past two decades. A few years ago, John Dudley launched the idea of composing a new data table focusing on the post-2000 developments in NLO as this could be a very useful resource for the research community. Starting from this idea, we have built a new set of data tables listing representative second- and third-order NLO parameter values taken from the literature since 2000 on the following material categories: bulk materials, 0D-1D-2D materials, metamaterials, fiber waveguiding materials, on-chip waveguiding materials, and hybrid waveguiding systems.[2] Besides tabulating nonlinearities measured at optical wavelengths, we have also included THz measurements in the tables. In addition, we have listed best practices for conducting NLO experiments and for reporting the obtained results.[2] These best practices define the selection process that we used for including papers in the tables. The data tables and best practices form the basis for a more adequate comparison, interpretation, and practical use of reported NLO parameters, and can as such stimulate the development of new NLO materials, devices and systems for real-life applications in optical data communication, signal processing, metrology, medical imaging, sensing, quantum light generation, and many other areas.

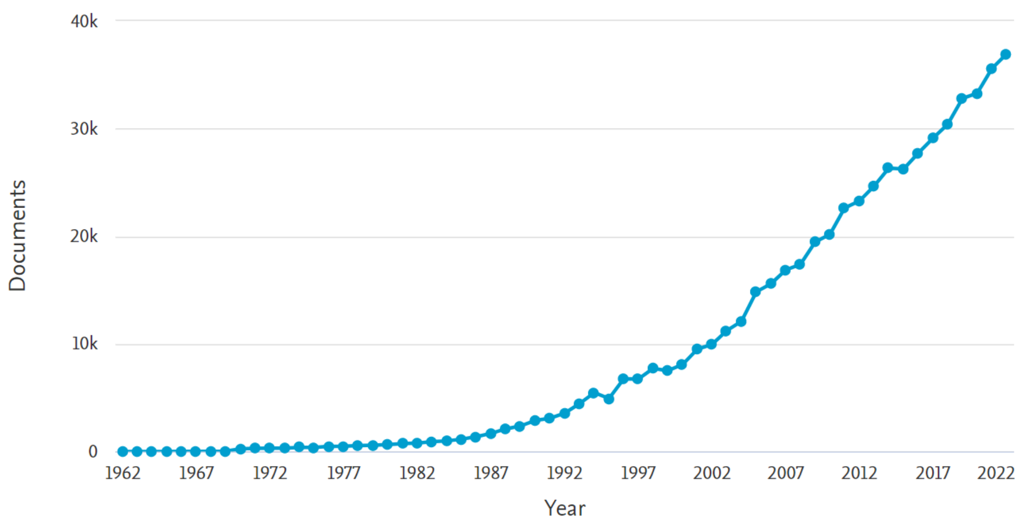

Figure 1. Number of NLO publications since 1961 (source: Scopus).

2. DATA TABLES AND BEST PRACTICES

This project has been carried out along the following step-by-step approach: first, we listed general best practices for NLO material characterization regardless of the NLO technique used. We subsequently identified technique-specific best practices, as measurements performed with e.g. the Z-scan technique or third-harmonic generation each have distinct requirements. Next, with the best practices in mind, we searched the post-2000 literature on NLO and selected representative experimental works reporting second- and/or third-order NLO coefficients for bulk materials, solvents, 0D-1D-2D materials, metamaterials, fiber waveguiding materials, on-chip waveguiding materials, and hybrid waveguiding systems. Besides tabulating NLO coefficients, we also included NLO conversion efficiencies reported for wave-mixing techniques. Finally, the data that each co-author had listed were cross-checked by another co-author to minimize errors. To illustrate the typical layout of the resulting data tables, Figure 2 shows an excerpt of the data table for fiber waveguiding materials (in this example, values are given for the Brillouin gain and the corresponding Brillouin frequency shift and linewidth). The final outcome of this project comprises 8 data tables for 8 material categories and an overview of general and technique-specific best practices.[2] Each data table is also accompanied by an introductory text providing relevant background information prior to 2000, a discussion of the trends after 2000 and general recommendations for future NLO research.[2]

While the tables indeed demonstrate major advances in NLO research since 2000, we would like to encourage the research community to implement the listed best practices in future NLO material characterization experiments. For example, measuring the wavelength dependence of the materials' NLO response is very helpful to unravel the physical processes contributing to the observed nonlinearities.[2] By complementing the data tables with a list of best practices and recommendations for future experiments, we hope to advance NLO research both in terms of fundamental science and practical applications.

		Fiber Properties		Measurement Details		Nonlinear Properties	
Material	Method	Length Loss	Core index contrast Cladding material Core Size Effective area	Wavelength	Pulse properties/ CW	$g_{Brillouin}$ Frequency shift Linewidth	Reference
As_2S_3	SpBS Linewidth	2 m 0.2 dB/m	0.26 NA As-S glass 6.1 μm 26 μm^2	2000 nm	CW	1.17×10^{-9} m/W 6.21 GHz 25 MHz	Deroh 2020
As_2S_3	SpBS Linewidth	2 m 0.2 dB/m	0.26 NA As-S glass 6.1 μm 20 μm^2	1550 nm	CW	1.54×10^{-9} m/W 7.96 GHz 33 MHz	Deroh 2020

Figure 2. Excerpt of the data table for fiber waveguiding materials.[2]

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