Reply to comment on "Temporally resolved electro-optic effect"

S. P. Jamison

Accelerator Science and Technology Centre, CCLRC Daresbury Laboratory, Warrington WA4 4AD, UK

A. M. MacLeod

School of Computing and Creative Technologies, University of Abertay Dundee, Dundee DD1 1HG, UK

G. Berden

FOM Institute for Plasma Physics 'Rijnhuizen', Edisonbaan 14, 3439 MN Nieuwegein, The Netherlands

D. A. Jaroszynski

Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK

W. A. Gillespie

Division of Electronic Engineering and Physics, University of Dundee, Dundee DD1 4HN, UK

Received February 16, 2007; accepted February 21, 2007;
posted February 23, 2007 (Doc. ID 79982); published April 17, 2007

In our Letter [Opt. Lett. **31**, 1753 (2006)], we derived, in a very general way, the temporal electric field modifications due to the $\chi^{(2)}$ electro-optic effect; to maintain generality we did not seek to narrow our result to specific experimental conditions, nor did we make any assumptions about birefringence or polarization states. A description of specific experimental conditions can be simply obtained by applying an appropriate Jones matrix calculation. The results noted in the Comment of Yellampalle *et al.* [Opt. Lett. **32**, 1341 (2007)] are no more than a particular application of our general results. © 2007 Optical Society of America

OCIS codes: 320.7110, 190.2620.

In our Letter[1] we derived a formalism for describing the $\chi^{(2)}$ electro-optic effect in both the time and the frequency domain. We made no assumptions about the polarization state of the beam nor about the detection polarizers, but instead derived a description of the electro-optic effect in the principal axis frame of the material. Our reasons for so doing were to maintain a generality extending beyond standard THz experiments and because the application of standard Jones matrix techniques in conjunction with our result makes it almost trivial to obtain a description for any of the multitude of situations encountered in THz detection experiments. We therefore take exception to the statement in the Comment by Yellampalle *et al.*[2] that our work[1] is incomplete, a claim that appears to be based on our not explicitly addressing the Comment authors' very specific experimental conditions. On the contrary, as befits a paper in *Optics Letters*, we sought to address the substantive and significant issues in a very general context, and left the extension to specific experiments to be discussed elsewhere. The possible implication in the Comment's concluding paragraph that our Eqs. (6) and (7) are valid only for specific geometries must also be countered; it is clear from the derivation in our Letter that our equations are valid *irrespective* of the geometric arrangement of the crystal and polarization optics. To be applied correctly they should be used in conjunction with an appropriate formalism, such as Jones matrices, to separately describe the geometric arrangement.

The Comment also disputes our characterization of an expression that has previously been widely used in the literature as "incorrect." We agree that our direct comparison of the disputed expression with our Eq. (7) of our Letter was not appropriate; as was clear in our Letter, our expression refers to the field modulated by the EO effect alone, while in Refs. 3–6 the alternative expression is stated to include the additional effects of some arrangement of analyzing polarizers. However, we note that there has been no consistent description in the literature of what that orientation of polarizers (or EO crystal) must be, nor is there any indication of how such an expression has been derived. In particular, the requirement for the presence of birefringence has not previously been alluded to. We also agree with the Comment's conclusion that the disputed expression will in fact be valid for describing the EO effect in the presence of crossed polarizers and with additional (specific) birefringent elements, a conclusion that can be obtained from our result via a simple Jones matrix calculation. (Indeed, such a conclusion was implicit in our own discussion of experimental results analyzed with and without a $\lambda/4$ wave plate.[1]) In this light, we concede that we should not have made the direct comparison of our results with the previous expressions, and that as a consequence our statement that the commonly used equation "must be considered incorrect" is too sweeping.

Finally, we do not understand the statement that our Eq. (6) does not lead to a proper description of the

0146-9592/07/101343-2/$15.00

Comment authors' experimental observations. As they show themselves, correct treatment of our Eq. (6) [which leads to their Eqs. (1) and (2)] provides a good description of their experimental results. We also note that our theory has been successfully applied to other polarizer geometries as well (see, e.g., Refs. 7 and 8.

S. Jamison's e-mail address is s.p.jamison@dl.ac.uk.

References

1. S. P. Jamison, A. M. MacLeod, G. Berden, D. A. Jaroszynski, and W. A. Gillespie, Opt. Lett. **31**, 1753 (2006).
2. B. Yellampalle, K. Y. Kim, J. H. Glownia, and A. J. Taylor, Opt. Lett. **32**, 1341 (2007).
3. F. G. Sun, Z. Jiang, and X.-C. Zhang, Appl. Phys. Lett. **73**, 2233 (1998).
4. B. Ferguson, S. Wang, D. Gray, D. Abbot, and X.-C. Zhang, Microelectron. J. **33**, 1043 (2002).
5. S. P. Jamison, J. Shen, A. M. MacLeod, W. A. Gillespie, and D. A. Jaroszynski, Opt. Lett. **28**, 1710 (2003).
6. B. Yellampalle, K. Y. Kim, G. Rodriguez, J. H. Glownia, and A. J. Taylor, Appl. Phys. Lett. **87**, 211109 (2005).
7. G. Berden, S. P. Jamison, A. M. MacLeod, W. A. Gillespie, B. Redlich, and A. F. G. van der Meer, Phys. Rev. Lett. **93**, 114802 (2004).
8. S. P. Jamison, J. Shen, A. M. MacLeod, W. A. Gillespie, and D. A. Jaroszynski, Opt. Lett. **28**, 1710 (2003).