



International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

ISBN 978-3-902842-69-5

DOI: 10.25039/TR.226.2017

TECHNICAL REPORT

High-Speed Testing Methods for LEDs

CIE 226:2017

UDC: 535.24
535.243

Descriptor: Photometry
Spectrophotometry

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organization devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in about 40 countries.

The objectives of the CIE are:

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organizations concerned with matters related to the science, technology, standardization and art in the fields of light and lighting.

The work of the CIE is carried out by Technical Committees, organized in seven Divisions. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reported and reviewed, and plans are made for the future. The CIE is recognized as the authority on all aspects of light and lighting. As such it occupies an important position among international organizations.

LA COMMISSION INTERNATIONALE DE L'ECLAIRAGE

La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant environ 40 pays.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par Comités Techniques, organisés en sept Divisions. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in rund 40 Ländern.

Die Ziele der CIE sind:

1. Ein internationales Forum für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Messtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird durch Technische Komitees geleistet, die in sieben Divisionen organisiert sind. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind auf der ganzen Welt anerkannt.

Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen berichtet und überprüft werden, sowie neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

Published by the

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Babenbergerstrasse 9, A-1010 Vienna, AUSTRIA
Tel: +43(1)714 31 87
e-mail: ciecb@cie.co.at
www.cie.co.at

© CIE 2017 - All rights reserved



International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

ISBN 978-3-902842-69-5

DOI: 10.25039/TR.226.2017

TECHNICAL REPORT

High-Speed Testing Methods for LEDs

CIE 226:2017

UDC: 535.24
535.243

Descriptor: Photometry
Spectrophotometry

This Technical Report has been prepared by CIE Technical Committee 2-64 of Division 2 "Physical Measurement of Light and Radiation" and has been approved by the Board of Administration as well as by Division 2 of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 2-64 de la Division 2 "Mesures Physiques de la Lumière et des Radiations" et a été approuvé par le Bureau et Division 2 de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

Dieser Technische Bericht ist vom Technischen Komitee CIE 2-64 der Division 2 "Physikalische Messungen von Licht und Strahlung" ausgearbeitet und vom Vorstand sowie Division 2 der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist.

Any mention of organizations or products does not imply endorsement by the CIE. Whilst every care has been taken in the compilation of any lists, up to the time of going to press, these may not be comprehensive.

Toute mention d'organisme ou de produit n'implique pas une préférence de la CIE. Malgré le soin apporté à la compilation de tous les documents jusqu'à la mise sous presse, ce travail ne saurait être exhaustif.

Die Erwähnung von Organisationen oder Erzeugnissen bedeutet keine Billigung durch die CIE. Obgleich große Sorgfalt bei der Erstellung von Verzeichnissen bis zum Zeitpunkt der Drucklegung angewendet wurde, besteht die Möglichkeit, dass diese nicht vollständig sind.

© CIE 2017 - All rights reserved

The following members of TC 2-64 "High-speed testing methods for LEDs" took part in the preparation of this Technical Report. The committee comes under Division 2 "Physical Measurement of Light and Radiation".

Authors:

Heidel, G. (Chair)

Blattner, P.
Cariou, N.
Chou, P.-T.
Konjhodzic, D.
Ng, K.F.
Ohno, Y.
Poppe, A.
Sauter, G.
Schneider, M.
Sperling, A.
Young, R.
Zong, Y.

Germany

Switzerland
France
Chinese Taipei
Germany
Malaysia
USA
Hungary
Germany
Germany
Germany
Germany
USA

Advisors:

Bajorins, D.
Fong, A.
Ho, M.
Kang, J.
Muray, K.
Ohkubo, K.
Oshima, K.
Pan, J.
Rowland, B.

Netherlands
USA
Malaysia
Korea
USA
Japan
Japan
China
Finland

CONTENTS

Summary	VI
Résumé	VI
Zusammenfassung	VI
1 Introduction	1
2 Purpose of the report	1
3 Terminology	1
4 Factors influencing the LED performance	3
4.1 Electrical and optical driving conditions	3
4.2 Electrical driving conditions	3
4.3 Thermal conditions	5
4.4 Thermal resistance	8
4.5 Thermal impedance	10
4.6 Subsumption	11
5 Pulsed operating conditions	12
5.1 Operating conditions	12
5.2 Rated operating conditions	12
5.3 Single-pulse measurement	12
6 Industrial high-speed testing of LED devices	13
6.1 LED back end production testing	13
6.2 Environment control	14
6.3 Measurement procedures	14
6.4 Measurement geometry of high-speed automated LED testing machines	15
6.4.1 Integrating sphere	15
6.4.2 Averaged luminous intensity	16
6.5 Challenges	16
7 High-speed testing of LED chips on wafer	16
7.1 LED front end production testing	16
7.2 Environment control	16
7.3 Measurement procedure	17
7.4 Measurement geometry	17
7.5 Radiometry and spectral measurement	17
7.5.1 Integrating sphere	18
7.5.2 Huge Si detector	20
7.5.3 Fibre-optical prober	20
7.5.4 Microscope	21
7.5.5 Different probing types	21
7.6 Single-die testing	22
7.7 Multi-die testing	22
7.8 Tape testing	23
8 Correlation between measurements on different levels	24
9 Conversion of values obtained at rated operation conditions and real operating conditions	24
10 Uncertainty of measurement	25
10.1 Contributions from non-perfect instruments	25
10.2 Measurement models	25

10.2.1	Laboratory setup	26
10.2.2	Production setup	26
10.2.3	Predictive calculations	27
10.2.4	Production signal measurement	27
10.2.5	Example	28
10.2.6	Alternative method for wafers: lamp factors	29
11	Traceability.....	30
11.1	Metrological traceability.....	30
11.2	Metrological traceability chain	30
Annex A	Thermal management of LED applications	31
References		34

HIGH-SPEED TESTING METHODS FOR LEDS

Summary

There are significant differences between LED packages or LED chips and conventional light sources which require measurements under specific measurement conditions.

The absence of a heat sink allows only to use short current pulses for the optical measurements in order to avoid significant heating of the device under test. The readings under these pulsed conditions can be converted into values under the final application conditions e.g. by using the corresponding datasheet information. The high-speed measurement procedures necessary for high-volume production testing require also special measurement configurations. These are based on the recommendations of the Technical Report CIE 127:2007 or should at least be traceable back to these.

This report describes in detail the measurement procedures and configurations that can be used to perform high-speed measurements on LED packages and LED chips. Specific properties of LEDs which need to be considered (e.g. current and temperature dependency of electrical and optical properties) are also highlighted.

PROCEDURE DE MESURE A GRANDE VITESSE DES LEDS

Résumé

Il existe des différences significatives entre les LEDs en boîtiers ou les puces LEDs et les sources de lumière conventionnelles qui impliquent des conditions de mesures spécifiques.

Une absence de dissipateur thermique oblige à travailler avec de brèves impulsions de courant afin d'éviter l'échauffement du dispositif sous test. Les valeurs obtenues en mode pulsé pourront être ensuite converties en valeurs correspondant aux conditions de l'utilisation finale, par exemple en utilisant les données de la fiche produit. Les procédures de mesure en impulsionnel, nécessaires pour les tests de productions en série, demandent des configurations de mesures spécifiques. Ces configurations sont basées sur les recommandations du rapport technique CIE 127:2000 ou au moins raccordables à ces recommandations.

Ce rapport décrit en détail les procédures de mesures et les configurations qui peuvent être utilisées pour mesurer les LEDs en boîtiers ou les puces LEDs en impulsionnel. Les propriétés des LEDs qui doivent être prises en compte (c'est-à-dire le courant et la dépendance en température des propriétés électriques et optiques) sont aussi détaillées.

HOCHGESCHWINDIGKEITSMESSMETHODEN FÜR LEDS

Zusammenfassung

Wesentliche Unterschiede zwischen LED Bauteilen oder LED Chips einerseits und konventionellen Lichtquellen andererseits erfordern Messungen unter spezifischen Bedingungen.

Die Abwesenheit einer Wärmesenke erlaubt für die Durchführung der optischen Messungen nur die Verwendung kurzer Strompulse, um eine wesentliche Erwärmung der Testobjekte zu vermeiden. Die Messwerte für diese gepulsten Messbedingungen können, z.B. unter Verwendung entsprechender Datenblattinformationen, in Werte für die endgültigen Anwendungsbedingungen umgerechnet werden. Die für Hochvolumen-Produktionstests erforderlichen Hochgeschwindigkeits-Messprozeduren erfordern ebenfalls spezielle Messanordnungen. Diese basieren auf den Empfehlungen des Technischen Berichts CIE 127:2007 oder sollten zumindest auf diese zurückgeführt werden können.

Dieser Bericht beschreibt detailliert die Messprozeduren und -anordnungen, mit denen Hochgeschwindigkeitsmessungen an LED Bauteilen und LED Chips durchgeführt werden können. Spezifische Eigenschaften von LEDs, die berücksichtigt werden müssen (z.B. Strom- und Temperaturabhängigkeit elektrischer und optischer Eigenschaften), werden ebenfalls erläutert.

1 Introduction

This report and the Technical Report CIE 225:2017 on optical measurement of high-power light emitting diodes (HP-LEDs, see 3.3) (CIE 2017) are intended to extend the scope of the technical report CIE 127:2007 on Measurement of LEDs (CIE 2007). This document deals with optical measurement of LEDs and high-power LEDs on wafer and at product level using pulse methods in the production environment. It does not describe the measurement methods for laboratories; such information can be found in (CIE 2017). The focus is on measurements during mass LED production for the purpose of LED sorting according to their different optical, colorimetric, and electrical properties, which is often referred to as the binning process. CIE 225:2017 covers the laboratory measurements of high-power LED products using DC methods. Both the pulse methods described in this document and the DC methods described in CIE 225:2017 reference measurements to the junction temperature of the LED.

Due to the very complicated LED production processes, starting from growing the epitaxial layers, via chip processing and final die packaging (die bond, wire bond, encapsulation, etc.) combined with the usage of various materials, it is necessary to test all LEDs to ensure a high quality in terms of specified colour, brightness, and voltage.

Since today's LED manufacturing processes suffer from process variations which are higher than accepted by the market, the LEDs must be sorted into various groups with narrow ranges of brightness, colour and other parameters, such as forward voltage, during the outgoing testing process. This leads to the need for precise and very fast testing methods and test equipment.

All optical and electrical parameters of solid-state light sources are highly temperature-dependent. This means that definitions of the test environment and driving conditions are necessary to give results which can be reproduced in other facilities with low uncertainty, and can be used to calculate optical values for the later applications.

2 Purpose of the report

The purpose of this report is to give recommendations for the testing of LEDs during production and the information that should be given to correctly interpret the results of these measurements. This is necessary especially due to the fact that ideal testing of light-emitting areas at a fixed, constant, temperature within around a 10-ms period is not possible. The rated operating conditions applied during the outgoing tests of LEDs at chip or package level usually do not and cannot completely correspond to typical operating conditions once the LEDs are assembled in their final application, which provides the thermal management necessary, e.g. for DC operation.

Within this report it will be shown that by proper specification of measurement conditions, including a proper definition of certain time settings, highly reproducible measurement results (necessary for good correlation between different levels of integration) can be achieved.

3 Terminology

For the purposes of this document the terms and definitions given in CIE S 017/E:2011 (CIE 2011a) and CIE S 017-SP1/E:2015 (CIE 2015b), and the following apply.

3.1

LED epi-wafer

compound semiconductor epitaxial film grown on suitable substrate.

3.2

LED-processed wafer

wafer with chip fabrication process before separation into single LED dice

3.3

high-power LED **HP-LED**

LED package that requires a heat sink or other means of thermal management for their normal operation

Note 1 to entry: A high-power LED is typically equipped with a dedicated cooling surface through which heat is transferred during normal operation.

3.4

chuck **carrier**

movable stage to hold the LED-processed wafer in electrical contact

3.5

SOT **Start Of Test**

signal sent from test handler to test system to start test sequence

3.6

EOT **End Of Test**

signal sent from test system to test handler indicating that the test sequence is completed

3.7

fixture

mechanical part of the test station or handler, containing a test nest with some clamps to hold the device under test during testing and to contact the device under test to supply the current

3.8

contact pin **contact**

thin needle for contacting the LED lead

3.9

source measure unit **SMU**

test instrument which is capable of both sourcing and measuring electrical quantities at the same time

3.10

optical test head

entrance optic of optical test equipment,

EXAMPLES: Geometries according to CIE 127:2007.

3.12

hand test station

site to handle devices under test manually and to position them one by one into a fixture

3.13

test handler

machine to handle and to position the devices under test automatically into a fixture with the contacts in front of the test head

3.14

test station

position of the fixture in an automatic test handler or manual test handler where the fixture is exactly aligned to the optical test head

3.15 sorter

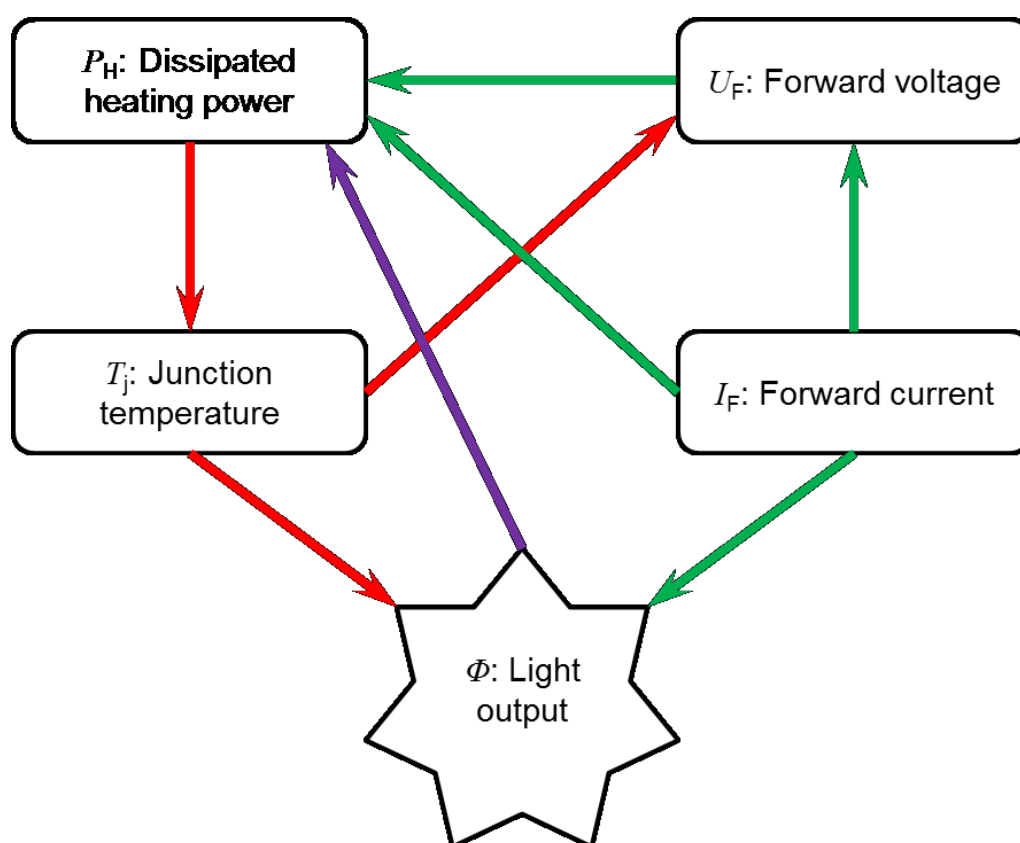
machine which is responsible to segregate the tested LEDs into physical bins according to the bin information from the test equipment

4 Factors influencing the LED performance

4.1 Electrical and optical driving conditions

Figure 1 shows the mutual dependence of electrical and optical parameters (note: parameters expressing colour are not explicitly mentioned in this diagram). In the next subclauses the consequences of varying forward current, I_F , or pn-junction temperature, T_J , will be described.

All statements for luminous flux in the following subclauses are also valid for luminous intensity; only luminous flux is discussed here.



NOTE Colour of the arrows: red: temperature; green: current; violet: optical power

Figure 1 – Mutual dependence of LED major operating characteristics

4.2 Electrical driving conditions

Due to the electrical diode characteristics, LEDs should be, and usually are, driven at constant forward current (DC or pulsed), also referred to as *current generator driven* mode of operation. All key parameters of an LED – voltage, total light output, and in almost all cases the colour of the emitted light – depend on the supplied electrical forward current, I_F . Figure 2 to Figure 4 show the typical I_F -dependence of the forward voltage, U_F , relative total luminous flux, $\Phi_V(I_F) / \Phi_V(I_{F,r})$, and dominant wavelength (colour) shift for a red, green and blue LED, respectively ($I_{F,r}$: forward current, I_F , at rated conditions). Since data are shown for a constant pn-junction temperature, $T_J = 25\text{ °C}$, packaging is irrelevant, so these figures represent a bare LED chip as well as a complete LED package or module.

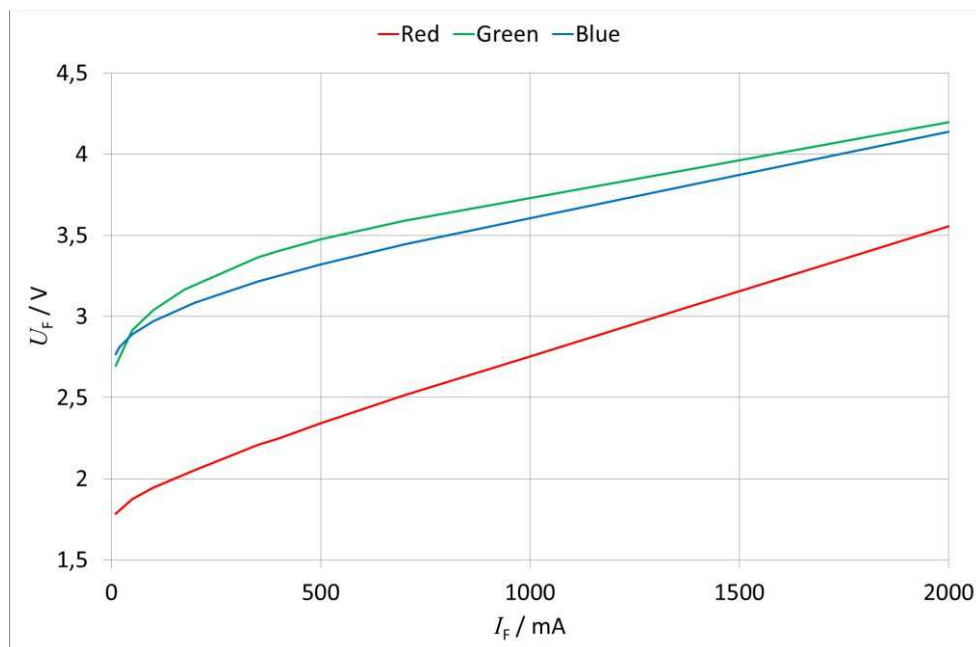


Figure 2 – Typical $I_F(U_F)$ characteristics of a red, green and a blue LED, corresponding to a junction temperature $T_J = 25\text{ °C}$

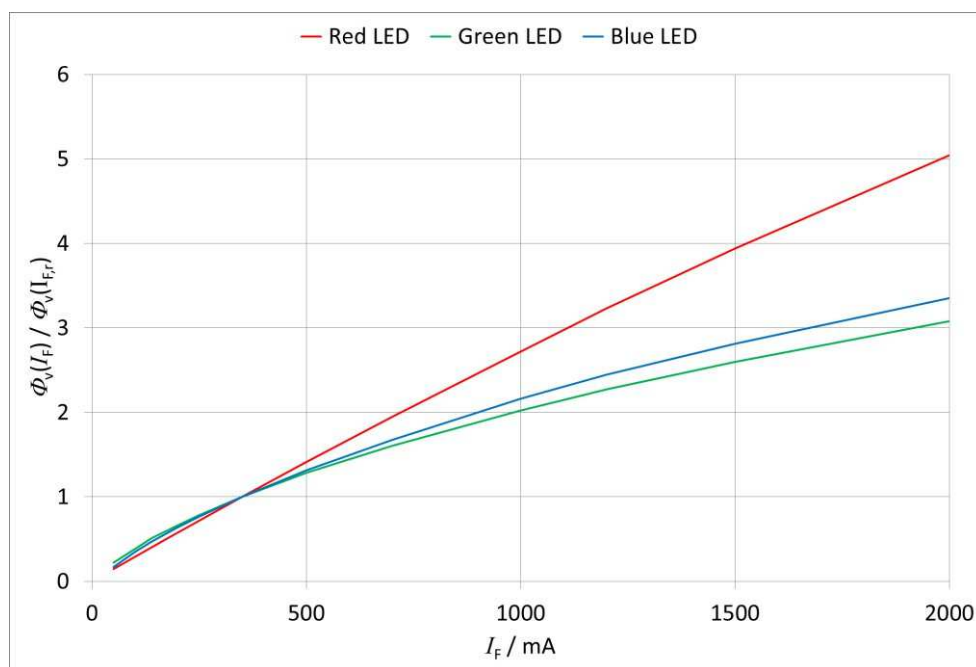


Figure 3 – Typical forward current (I_F) dependence of the relative luminous flux of a red, green and a blue LED, corresponding to a junction temperature $T_J = 25\text{ °C}$