Expertise
for the establishment of an IEEE Milestone in recognition of the discovery of the rectifier effect of a metal-semiconductor junction at the Thomas School in Leipzig in 1874

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The proposed milestone at the Thomasschule in Leipzig for „Unipolar conduction of metal-semiconductor junctions“ will represent a significant technical achievement. In the paper with the title “Ueber die Stromleitung durch Schwefelmetalle” (About the conduction of current through metal sulfides), submitted to `Annalen der Physik and Chemie‘ on 23 November 1874 Ferdinand Braun reported the observation that the electrical resistance of various natural and synthetic metal sulfide samples was dependent on direction, intensity and duration of the electrical current. The measured disparity of the currents has been up to 30 percent [1].

Since 1872 Ferdinand Braun worked as an assistant at the University Würzburg. The research activities of Ferdinand Braun mainly were focused on problems of electric conductivity. After working two years Würzburg, he accepted in fall 1874 a safe and well-paid teaching appointment to the St. Thomas Gymnasium (Thomasschule), a public boarding school in Leipzig, Saxony, Germany. It was founded by the Augustinians in 1212 and is one of the oldest schools in the world [2]. This Humanistic Gymnasium has a very long list of distinguished former students, including Richard Wagner (1813–1883) and many members of the Bach family, including Johann Sebastian Bach's son Carl Philipp Emanuel Bach (1714–1788). Also during his engagement as a Gymnasium teacher Ferdinand Braun continued his scientific work. Ferdinand Braun could have carried out his experiments in the physical cabinet of the Thomas School or in his apartment at what is now Friedrich-Ebert-Strasse 8. Biographies of Ferdinand Braun are presented in [3, 4, 5, 6, 7]. The scientific work of Ferdinand Braun in Leipzig is certainly based on preliminary work in Würzburg.

With the publication title “Ueber die Stromleitung durch Schwefelmetalle”, Ferdinand Braun contributed the basic work of modern solid-state electronics. It should be borne in mind that although he had the opportunity to continue his scientific research at the Thomasschule, he was not embedded in an environment that could have been conducive to his scientific work through exchanges with specialist colleagues. Within the environment of the excellent Thomasschule, which, however, had a primarily humanistic and not scientific orientation, we can assume that he was completely on his own in his investigations and must also acknowledge his achievement as a special one in this regard.

In the following, several researchers investigated the unipolar conductivity under different conditions and with other materials. Werner Siemens obtained similar results with selenium if both electrodes applied to the crystal differed considerably in size [8]. Braun reacted on this with a paper about the deviations from Ohm’s law in solids with metallic conductivity [9]. In this paper he concluded

> *„In general the anomalous effects occur in the easiest way if at least one electrode is small. Therefore in the majority of cases I have used as the one electrode a wire which has been pressed by a spiral spring enclosed in a bushing against the crystal. Depending on the steadiness of the material a pressure of up to one kilo has been applied. In other experiments a mercury contact has been chosen. In further experiments the crystal surface has been covered galvanoplastically with a thin copper layer and this has been overlayed with mercury. The effects are mostly, if*

not always, determined by the junction region. At this place a very considerable current dependent resistance is localized.“

Thus Ferdinand Braun has discovered the point contact rectifier effect and by this way created the whisker diode.

Undoubtedly, the Thomas School should be acknowledged as the place where the unipolar conductivity of a metal-semiconductor contact was discovered. The special circumstances of Ferdinand Braun's connection with this discovery justify the naming of Ferdinand Braun in the table.

The proposed citation is:

> “In the physics laboratory of the Thomas School in Leipzig in November 1874, Ferdinand Braun reported the observation that the electrical resistance of an arrangement of a wire electrode pressed by a spring against a metal sulfide crystal was dependent on direction, intensity and duration of the electrical current. This discovery of the rectifying action of a semiconductor barrier marks the beginning of solid state electronics.”

When Ferdinand Braun published his paper on unipolar conductivity in metal sulfides this effecxt has had no technical application, and also the physical laws governing this effect have not been known for the next fifty years. However, with his experiments performed with copper sulfide and other materials Ferdinand Braun has been the first one who has reported rectifying action of a semiconductor barrier. Ferdinand Braun had not yet thought of a technical application of the effect he had discovered. Eight years before Heinrich Hertz experimentally demonstrated electromagnetic waves, the time was not yet ripe. The first technical application of the solid-state rectifier effect was made by Jagadis Chandra Bose twenty years later. Bose used galena (lead sulfide) crystals contacted by a metal wire to demonstrate transmission and reception of electromagnetic waves at 60 GHz, over a distance of 23 meters [10]. An IEEE milestone referring to the "First millimeter wave communications experiments by J.C. Bose, 1894-96” was posted at the Presidency College in Kolkata on September 15, 2012.

In 1928 Sommerfeld [11] and in 1929 Felix Bloch [12] provided an understanding of the properties of solids on the basis of quantum mechanics. Finally, upon this basis in 1939 Walter Schottky presented a semiconductor theory of the junction and peak rectifiers [13]

Justification for inclusion of the name “Ferdinand Braun” in the citation:

The proposal includes detailed, clearly stated, and incontrovertible evidence, particularly historical evidence and documentation, that Ferdinand Braun was not only central to the achievement but the singular person who has done alone all the research work. Therefore, Ferdinand Braun undoubtedly deserves to have his name mentioned on the milestone. This does not leave out anyone who should be expressly named on the plaque.

The evidence for inclusion of the name “Ferdinand Braun” in the citation supported by the following references and the attached copies of the referenced documents:

- In their article “History of Semiconductor Research“ [14], G.L. Pearson and W.H. Brattain wrote: *“In 1874 came the discovery that contacts between certain materials would rectify, or more precisely, that the resistance did not obey Ohm's law but depended on the magnitude and sign of the applied voltage. F. Braun observed this for contacts between metals and various sulfides such as galena and pyrites, and A. Schuster for contacts between untarnished and tarnished (probably copper oxide) copper wires.“*

- In their article ”Electrical interface barriers” [15], T.C. McGill and C.A. Mead wrote: *“The study of electrical interface barriers dates back to 1984, when K.F. Braun observed that an interface formed bby a metal wire brought into contact with a lead sulfide crystal carried current more easily in one direction than in the other.”*
- In his article “About the beginnings of wireless“ [16], F.E. Gardiol wrote *“While improving upon the operation of his equipment, Bose introduced an impressive number of specialized devices for millimeter waves, such as waveguides, horn antennas, dielectric lenses, interferometers, couplers, absorbers, etc. - devices still in use nowadays. In 1899, he developed a sensitive “iron-mercury-iron” coherer. Later on, he used a galena detector in his receiver, making use of the rectification properties of contacts between a metal and sulfites - discovered in 1874 in Strasburg by professor Karl Ferdinand Braun (1850-1918).“* Here F. Gardiol, who correctly represented the importance of Ferdinand Braun's contribution to solid-state electronics, made a mistake in relation to the location. Ferdinand Braun was not called to Strasbourg until 1880, where he then made other important inventions - the Braun tube and the coupled resonant circuits.
- In his article “History of Infrarwed detectors“ [17], A. Rogalski wrote *“Rectifying properties of semiconductor-metal contactwere discovered by Ferdinand Braun in 1874, when he probed a naturally-occurring lead sulphide (galena) crystal with the point of a thin metal wire and noted that current flowed freely in one direction only.“*
- In the book chapter „Historical German contributions of electromagnetic oscillations and waves“ [18], M. Thumm wrote „In 1874 K.F. Braun discovered conductioin and reectification in metal sulfid crystals that occurred when the crystal was probed by a metal point (whisker). On November 14, 1876 he demonstrated his rectification effect of a metal-semiconductor contact at Leipzig to a broad audience but his work was not recognized at that time.“

These referenced and submitted documents confirm unequivocally the justification for inclusion of the name “Ferdinand Braun” in the citation and confirm support for including the name “Ferdinand Braun” as proposed in the citation.

The discovery of the effect of unipolar conduction of metal-semiconductor junctions at the Thomasschule in Leipzig in 1874 and and the first reported of this discovery by Ferdinand Braun in the same year marks the starting point of modern solid-state electronics. An IEEE Milestone should focus attention on the location of the discovery while also pointing out the unique research personality Ferdinand Braun.

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