***Title of the proposed milestone:***

Commercialization of Multi-Layer Ceramic Capacitors with Nickel electrode (Ni-MLCCs), 1982.

***Plaque citation summarizing the achievement and its significance:***

Murata Manufacturing Co., Ltd. released new Ni-MLCCs in 1982, and has since been the world's leading manufacturer of Ni-MLCCs. Through innovations of capacitance enhancement, fabrication miniaturization, and cost reduction, the world annual production of Ni-MLCCs has risen to 3 trillion, according as their utility is expanding in computer/network devices, home appliances, industrial equipment, and medical instruments. Now, Ni-MLCC is the key element indispensable to all electronics devices.

***What is the historical significance of the work (its technological, scientific, or social importance)?***

The major historical significance of Murata's commercialization of Ni-MLCCs is briefed as follows.

1. Historical background of the birth of Ni-MLCCs:
The discovery of the barium titanate ($BaTiO_3$) ceramics with high dielectric quality in 1944 triggered the development of a series of *multi-layer ceramic capacitors* (MLCCs), such as those with Pt (platinum), Pd (palladium), and Ag (silver)-Pd electrodes, in the 1960s through the early 1970s mainly for military and industrial use because of their extremely high material prices. Although the MLCC with Ag-Pd electrode was the cheapest of all MLCCs at that time, the material prices of both Ag and Pd were skyrocketing due to the 1973 oil crisis, and hence a much cheaper base metal was thirsted to be substituted for the Ag-Pd alloy. Seeing that the necessary condition for a metal to be used for the internal electrode of MLCC was that it could be co-sintered with the dielectric material at low oxygen partial pressure, Murata began to develop a new MLCC with a base metal electrode in 1974.

2. Selection of Ni for electrode and development of new MLCCs:
Murata first focused on *nickel* (Ni) as a feasible candidate for the electrode of MLCC because of its very low price, and then tried to develop a dielectric material to compose MLCC with this Ni electrode, until in 1975 Murata successfully acquired the new dielectrics made of $BaTiO_3$ ceramics with its composition BaO partly displaced by CaO [1]. Through fabrication reformations [2, 3], Murata attained newly-made dielectrics which exhibited an excellent insulating performance even if co-sintered with Ni electrode. Eventually, in 1982 Murata embarked on the mass production, therefore the commercialization, of the new MLCCs with Ni electrode (Ni-MLCCs) [1, 4].

3. Achievements of commercializing new Ni-MLCCs:
Noting that as compared with the material price of Ag-Pd alloy, that of Ni was almost 1/300 in the early 1980s, it can be seen that Murata's new Ni-MLCCs would extremely reduce the fabrication cost. In addition, due to the progress of the miniaturization technology as well as the surface mount technology, the industrial demands for the Ni-MLCCs grew so drastically that Murata attained the global lead in the commercialization of Ni-MLCCs. Owing to Murata's outstanding achievements

of developing the new Ni-MLCCs, Mr. Y. Sakabe, a chief engineer at Murata, won the Fulrath Award from the American Ceramic Association in 1986, and Murata also received the Corporate Technical Achievement Award at the American Ceramic Association's 100th Annual Meeting in 1998 [5].

***What obstacles (technical, political, geographic) needed to be overcome?***

1. Obstacle to improving the quality of Ni-MLCCs:

Even after Murata successfully found a useful dielectric material in 1975, there still remained the hard problem of how to enhance the capacitance of the new Ni-MLCC. To cope with this difficulty, Murata tried to increase the capacitance density of Ni-MLCC not only by reducing the dielectric/electrode thickness but also by augmenting the number of layers. Eventually, in 1982 Murata successfully embarked on the mass production of the new Ni-MLCCs [1, 4].

2. Obstacle to maintaining the reliability:

Centralab Inc. (Milwaukee, USA) released Ni-MLCCs in 1979, which unfortunately caused a fatal accident of deteriorating the insulation characteristics, resulting in the production stoppage [6]. Motivated by this incident, Murata concentrated much on developing reliable Ni-MLCCs, until they successfully attained new Ni-MLCCs, in which the dielectrics displayed an excellent insulating performance even if co-fired with the Ni electrode. Thus Murata's new Ni-MLCCs exhibited their high insulation characteristics [4, 5].

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***What features set this work apart from similar achievements?***

There are a number of distinctive features of Murata's Ni-MLCCs as summarized below.

1. Unique device performances of the new Ni-MLCCs:

Adopting Ni as the electrode of MLCC, Murata realized a much cheaper MLCC, as already stated. After attempts of reducing the dielectric/electrode thickness as well as of augmenting the number of layers, Murata managed to enhance the capacitance of the new Ni-MLCC [4, 5]. Thus Murata distinctively achieved not only the fabrication cost reduction but also the capacitance enhancement of Ni-MLCCs.

2. Contribution to social life:

The applications of Ni-MLCCs have been widely expanded not only for industrial and medical use but also for commercial use, such as for home appliances, PCs, cameras, wearable devices, mobile terminals, etc. Now that more than 1000 Ni-MLCCs can be embedded in only one smart phone, it can be seen that Ni-MLCCs have greatly contributed to the miniaturization and cost reduction of numerous mobile terminals, and therefore to user's convenience.

3. Contribution to market demands:

Centralab's Ni-MLCCs released in 1979 caused a serious trouble of deteriorating the insulation characteristics [6], whereas Murata's new Ni-MLCCs maintained the quality of insulation characteristics for a long period. Hence, the industrial demands for the new Ni-MLCCs increased

so rapidly that the market scale was extensively expanded, and hence Murata has attained the global lead in the commercialization of Ni-MLCCs [5].

References

[1] Y. Sakabe, “Nickel electrode ceramic capacitor”, Electronic Semiconductor, vol. 7. pp. 37-42, 1987 (in Japanese).

[2] Japanese Patent, No. 53-24600, “Non-reducing dielectric ceramic composition”, March 7, 1978 (in Japanese).

[3] U.S. Patent, No. 4115493, “Method for making monolithic ceramic capacitor employing non-reducing dielectric ceramic composition” September 19, 1978.

[4] D.M. Smith, “Multilayer ceramic capacitors with base metal electrodes”, in Proc. IEEE International Symp. on Applications of Ferroelectrics, pp. 369-373, 2000.

[5] Y. Sakabe, “Development of the multilayer ceramic capacitors with base metal electrode”, Abstract Book, the American Ceramic Association Society’s 100$^{th}$ Annual Meeting & Exposition, vol. 49, 1998.

[6] D.F.K. Hennings, “Multilayer ceramic capacitors with base metal electrodes”, Proc. IEEE International Symp. on Applications of Ferroelectrics, pp. 135-138, 2000.

Attachment

**Appendix 1**: Reference [1] was written in Japanese, for which English summaries are briefed as follows: Noting that as compared with the material prices of Pd and Ag-Pd electrodes, that of Ni was almost 1/700 and 1/300, respectively, in the early 1980s, it could be seen that the MLCC with Ni electrode would extremely reduce the fabrication cost. In addition, Murata managed to acquire the new dielectric material made of $BaTi_3$ ceramics with its composition BaO partly displaced by CaO, with which the Ni electrode could be co-sintered. Thus, adopting this dielectric material Murata successfully attained new MLCCs with Ni electrode (Ni-MLCCs), and hence embarked on the mass production of the new Ni-MLCCs in 1982.

**Appendix 2**: Reference [2] was written in Japanese, for which English summaries are briefed as follows: This patent describes the details of the method of non-reducing dielectric ceramic composition, by which Murata’s new Ni-MLCCs could be commercialized.